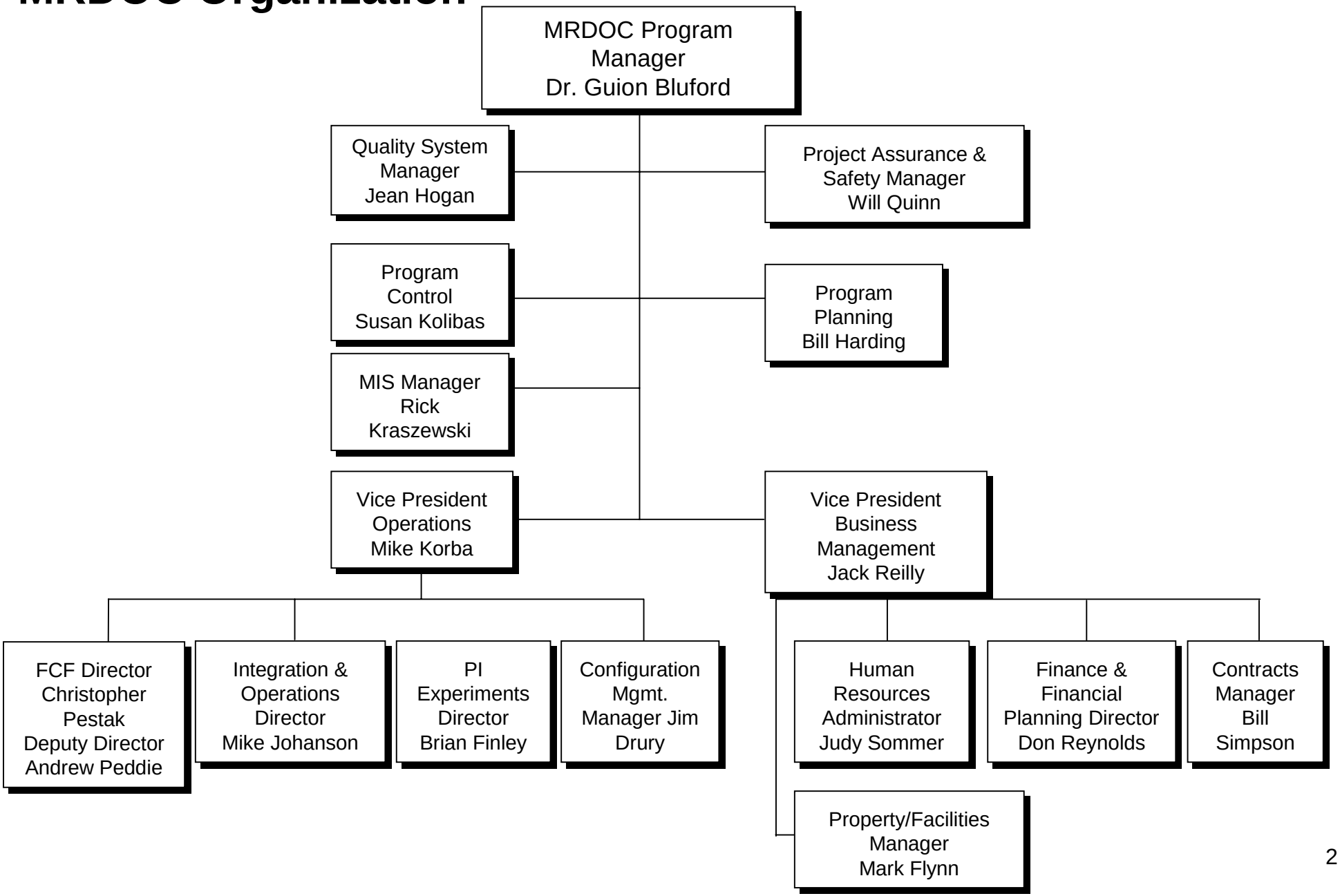
FCF System

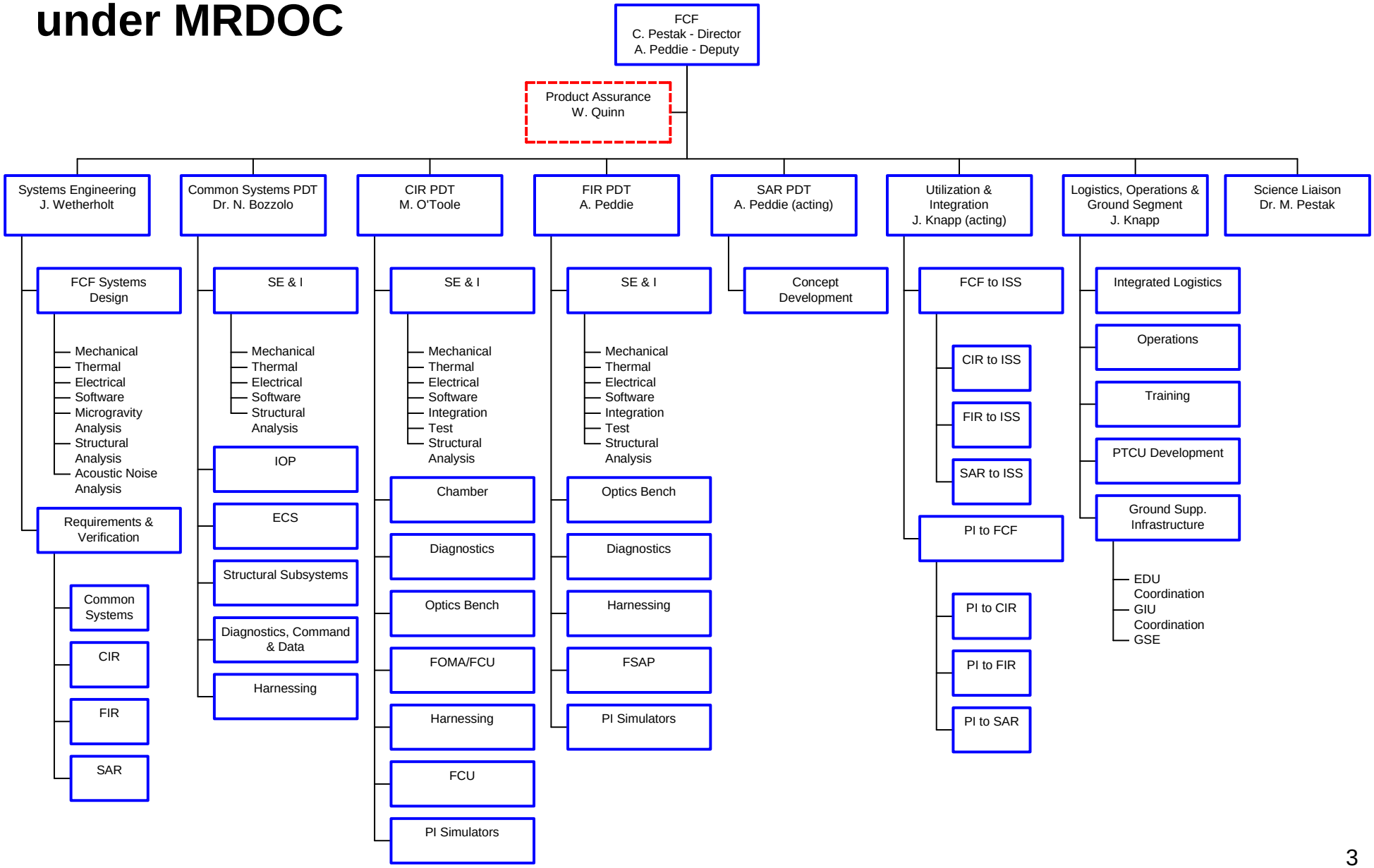
Chris Pestak

February 12, 2001

MRDOC Organization



FCF Project Organization under MRDOC



FCF Project Organization - FDC Team Contact List

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FCF Overview

FCF Acronym List

AMA	Atmospheric Measurement Assembly
ARIS	Active Rack Isolation Subsystem
ATCS	Air Thermal Control System
ATCU	Air Thermal Control Unit
CIR	Combustion Integrated Rack
DCM	Diagnostics Control Module
ECS	Environmental Control Subsystem
EDU	Experiment Development Unit
EM	Engineering Model
EMC	Electro- Magnetic Compatibility
EP	Experiment Package
EPCU	Electrical Power Control Unit
EPS	Electrical Power Subsystem
ESP	Electronic Support Package
ESSA	EPCU Shutoff Switch Assembly
EVP	Exhaust Vent Package
FCF	Fluids and Combustion Facility
FCU	FOMA Control Unit
FDSS	Fire Detection and Suppression System
FEA	Fluids Experiment Assembly
FIR	Fluids Integrated Rack
FOMA	Fuel/ Oxidizer Management Assembly
FSAP	Fluid Science Avionics Package
GIS	Gas Interface System
GIU	Ground Integration Unit
GSE	Ground Support Equipment
HFR	High Frame Rate
HiBMs	High Bit depth Multi Spectral Camera Package
HR	High Resolution
H/W	Hardware
IAM	Image Acquisition Module
IOP	Input/ Output Processor
IPP	Image Processing Package
IPSU	Image Processing and Storage Uni
IR	Infraredt
ISPR	International Standard Payload Rack
ISS	International Space Station
ITCS	Internal Thermal Control System
LED	Light Emitting Diode
LLL	Low Light Level
LMM	Light Microscopy Module
MDCA	Multi-user Droplet Combustion Assembly
MFC	Mass Flow Controller
OB	Optics Bench
OM	Optics Module
OPI	Optics Plate Interface
ORU	Orbital Replacement Unit
PCS	Portable Computer System
PDC	Payload Development Center
PFE	Portable Fire Extinguisher
PI	Principal Investigator
PIV	Particle Image Velocimetry
PTCU	Payload Training Center Unit
REU	Remote Electronic Unit
RFCA	Rack Flow Control Assembly
RHA	Rack Handling Adapter
RIP	Rack Interface Panel
RMSA	Rack Maintenance Switch Assembly
RPC	Remote Power Controller
RPCM	Remote Power Controller Module
RUP	Rack Utility Panel
S/ W	Software
SAMS	Space Acceleration Measurement System
SAR	Shared Accommodations Rack
SSC	Station Support Computer
UIP	Utility Interface Panel
UV	Ultraviolet
VVS	Vacuum Vent System
WFCA	Water Flow Control Assembly
WTCS	Water Thermal Control System

FCF Mission

Support sustained, systematic microgravity fluid physics and combustion research on board the ISS in the following areas:

Fluid Physics

- Thermocapillarity
- Interfacial Phenomena
- Phase Change
- Complex Fluids
- Colloids
- Morphology
- Electrohydrodynamics
- Diffuso-Capillary
- Thermo-Diffuso-Capillary
- Multiphase Flow
- Granular Media

Combustion

- Laminar Flames
- Turbulent Combustion
- Reaction Kinematics
- Condensed Phase Organic Fuel Combustion
- Flame Spread and Fire Suppressants
- Droplet and Spray Combustion
- Soot and Polycyclic Aromatic Hydrocarbons

FCF Overview

- The FCF is a modular, multi-user facility being developed by GRC for permanent installation in the ISS US Lab Module to support microgravity fluid physics and combustion science.
- FCF establishes an initial operational capability for microgravity fluid physics and combustion science on-board ISS. The Project's scope is through the design, development, production, deployment and initial operation in ISS.
- The FCF Project transitions to a steady-state utilization program after on-orbit acceptance of the last FCF rack deployed.
- The FCF system consists of a Flight Segment and a Ground Segment. The Flight Segment consists of three powered racks and sufficient on-orbit stowage in ISS for FCF and payload hardware.
- FCF operates together with payload experiment equipment, ground-based operations facilities and the FCF ground segment to perform fluids and combustion science experiments within available FCF and ISS resources.
- The FCF Ground Segment is required for operation of the FCF and for successful integration and operation of experiment hardware and software into the FCF Flight Segment.

Incremental Deployment of the FCF System

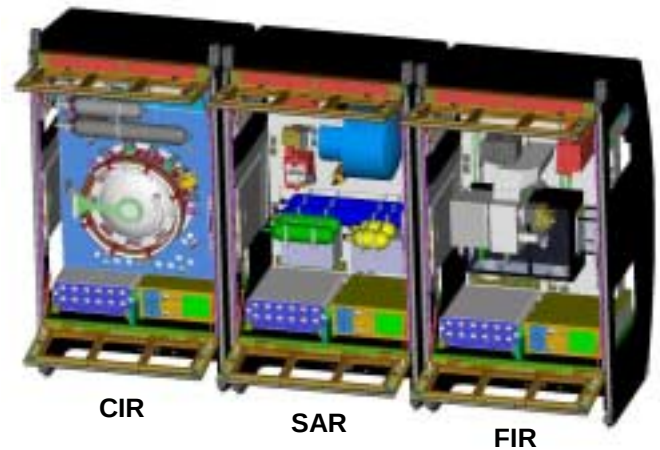
Conduct Combustion Experiments only on orbit.

Conduct Combustion Experiments and Fluids Experiments on orbit.

Conduct Combustion, Fluids Experiments And complete flight segment requirements.

Three-Tier Solution for a Diverse Complement of Science Requirements

Fluids and Combustion Facility

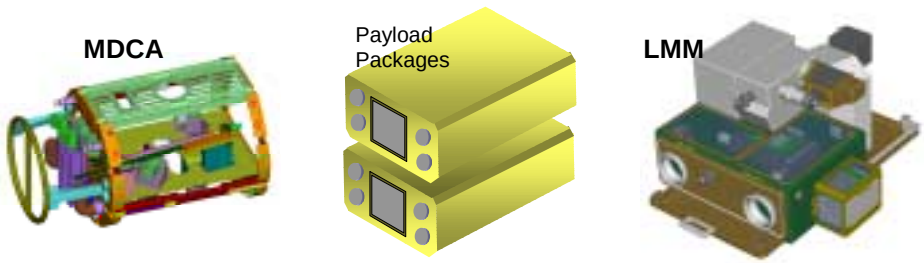


Tier 1

Systems commonly needed by nearly all Fluids and Combustion Experiments

- Build once, launch once, use forever

Multi-Use Experiment Hardware

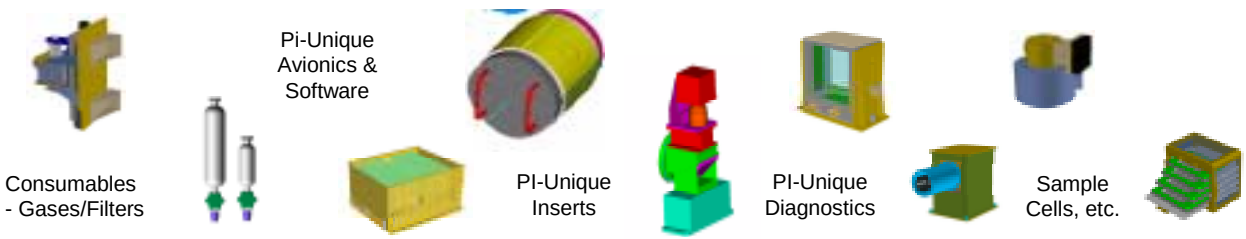


Tier 2

Multi-use experiment inserts customize FCF to a specific sub-discipline

- Build once, launch once per ~4 expts, reuse
- Other sub-discipline inserts reuse some equipment and concepts

PI Unique Equipment

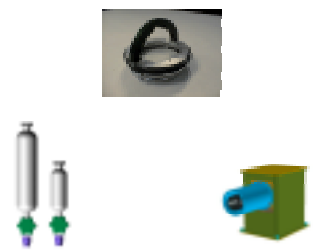


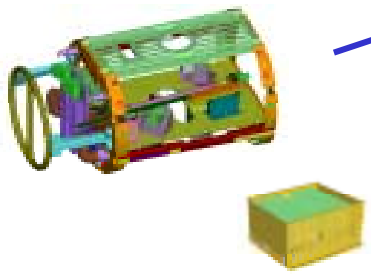
Tier 3

PI unique equipment

- Build and launch for each experiment
- May reuse or add to capability of FCF or multi-use inserts

Three-Tier Solution for Combustion





PI-Specific Equipment

- Fuels/Oxidizers/Consumables
  - Gaseous Fuels/Oxidizers
  - Liquid/Solid Fuel Supplies
  - GC check gases
  - Adsorber cartridge filters
- PI-Unique H/W & S/W
  - Specific avionics/software
  - Specialized diagnostics or modules (e.g., cameras, lenses, filters, optics, control avionics and software)
- Specific Instrumentation

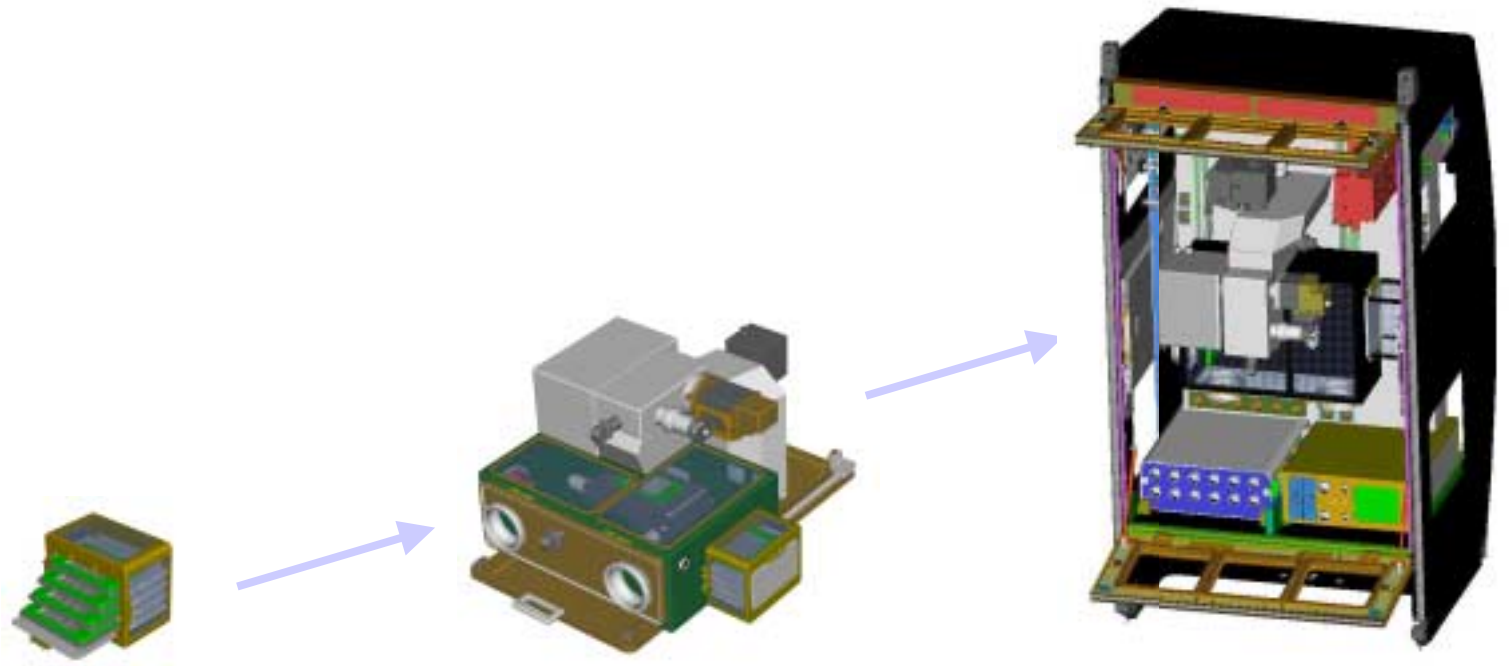
Multi-Use Insert (e.g., MDCA)

- Combustion Experiment Insert
  - Experiment orientation
  - Support structure
  - Flow ducts; test sections
- PI Avionics Package
  - Multi-use control electronics, motor drivers, etc.
  - Software modules
- Multi-Use Diagnostics / Lighting
  - e.g., Radiometers
  - PI-Unique illumination sources

FCF Combustion Integrated Rack

- Combustion Chamber
- Diagnostics
  - 8 standard locations (w/ SAR)
  - Image Processing & Storage
- Gaseous Fuel/Oxidizer Mgmnt.
  - Gas Supply & Blending
  - Exhaust Vent / GC
- Electrical Power Control Unit
  - Power Conditioning & Control
- Command & Data Handling
- Active Rack Isolation
- Environmental Control
  - Water/Air Cooling
  - Gas Interface/Fire Detection

Three-Tier Solution for Fluid Physics



PI Specific Samples

- Samples with supporting hardware
- Specific Conditioning
- Specific Diagnostic

Investigation Module (e.g., LMM)

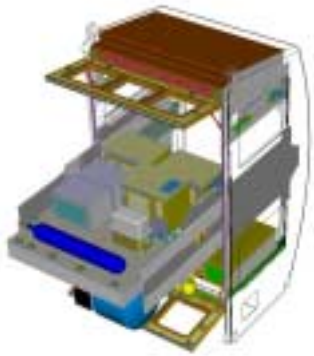
- Science Infrastructure (hardware/ software) items that uniquely meet the needs of the PIs
- Unique Diagnostics
- Specialized Imaging
- Fluid Containment

Fluids Integrated Rack

- Power Supply
- Avionics/Control
- Common Illumination
- PI Integration Optics Bench
- Imaging and Frame Capture
- Fluid Diagnostics
- Environmental Control
- Data Processing
- Frangibles and Laser Light Containment

FCF Shared Accommodation Rack

Science Support Volume
FCF and *Other* Science
Image Processing



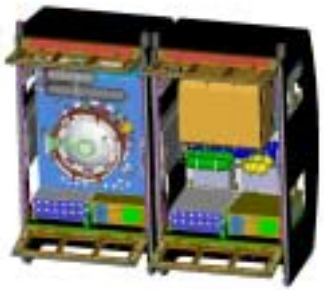
Advanced Diagnostic Volume
Shared Data Processing
Image Processing
Mass Data Storage

Additional Fluids Science
Gas/Fluid Storage

Laptop Computer Interface
Video Monitor Crew Interface
Science Imaging interface

Middeck locker Interface

Science Sample
Conditioning



CIR/SAR
Operate Together

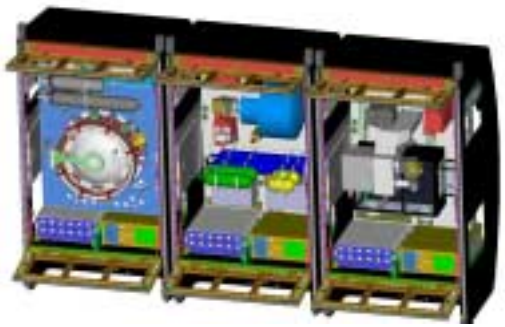
SAR

Crew Can Monitor
CIR/FIR Science
Activity Through SAR
Without Mechanical
Disturbance to Science

FIR/SAR
Operate Together

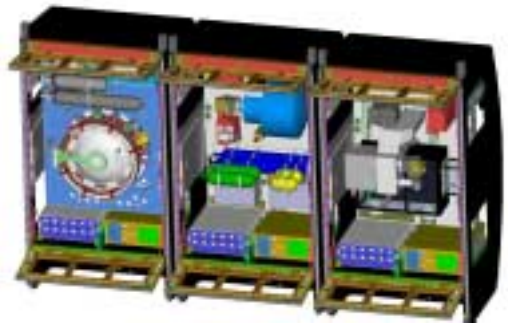
Multiple Image Processing
Configurations Allows for
new Diagnostics such as
High Speed Cameras
(1000+ fps) in science
elements

FCF Flight and Ground Segments



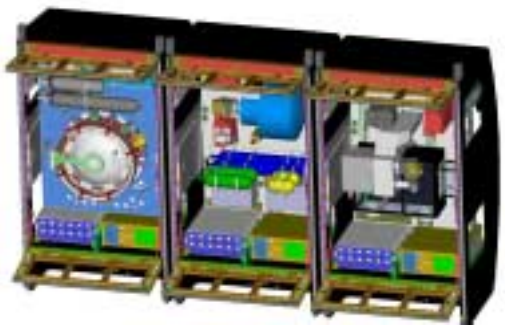
Flight Unit

FCF racks located on-orbit in the ISS US Laboratory Module.



Experiment Development Unit (EDU)

High fidelity FCF model located at GRC. Available to payload developers for a variety of tests including interface verification, preliminary configuration selection, test sequence determination. Also used for sub-rack payload engineering model testing.



Ground Integration Unit (GIU)

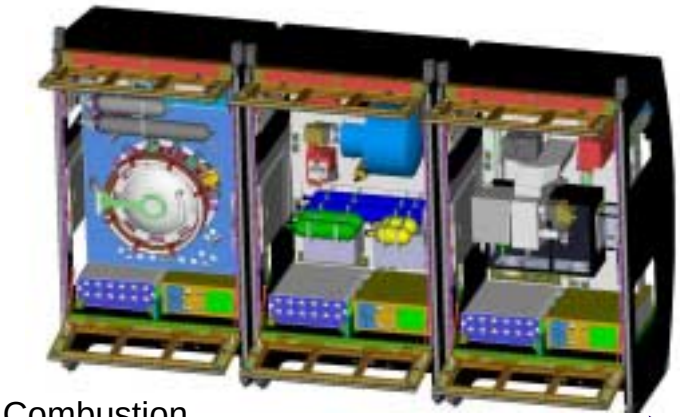
FCF flight-equivalent racks located at GRC. The GIU is used for final flight interface verification between sub-rack payloads and the FCF, as well as acceptance testing of PI hardware. The GIU configuration may be maintained for on-orbit troubleshooting. The GIU is flight equivalent, except aluminum ISPRs are used and ARIS is not functional in the GIU.

Payload Training Center Unit (PTCU)

FCF training racks are located at JSC and used to train astronauts on FCF and sub-rack payload flight procedures. PTCU racks are supplemented with partial task trainers to prepare the ISS crew for experiment-specific operations.

FCF Ground and Flight Segments

ISS Fluids and Combustion Facility



Combustion Integrated Rack | Shared Accommodations Rack | Fluids Integrated Rack

Flight Segment

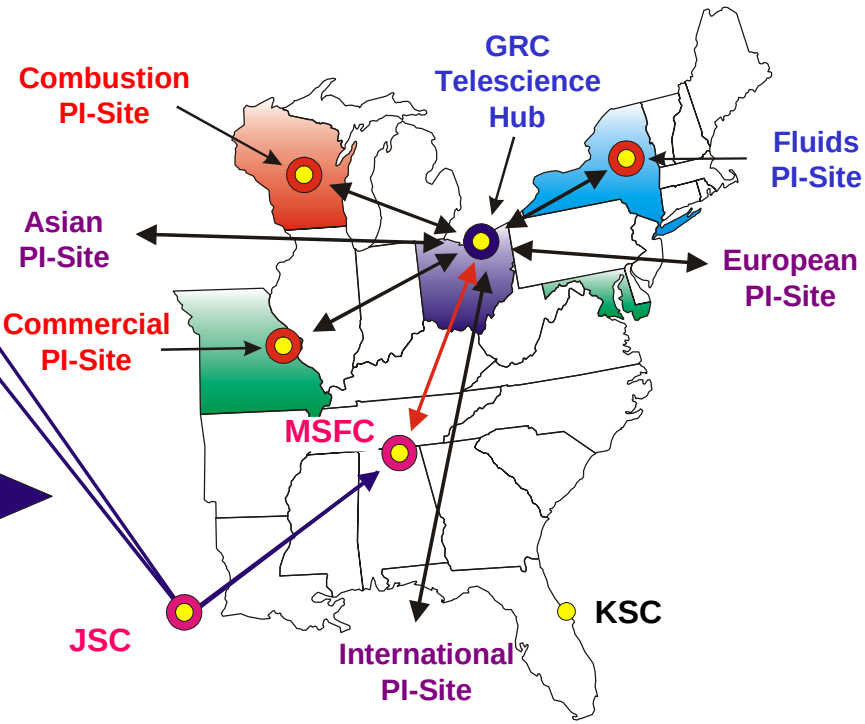
Space Station Based Equipment

- Combustion Integrated Rack
- Fluids Integrated Rack
- Shared Accommodations Rack
- Spares & Other Equipment

Ground Segment

Earth Based Operations

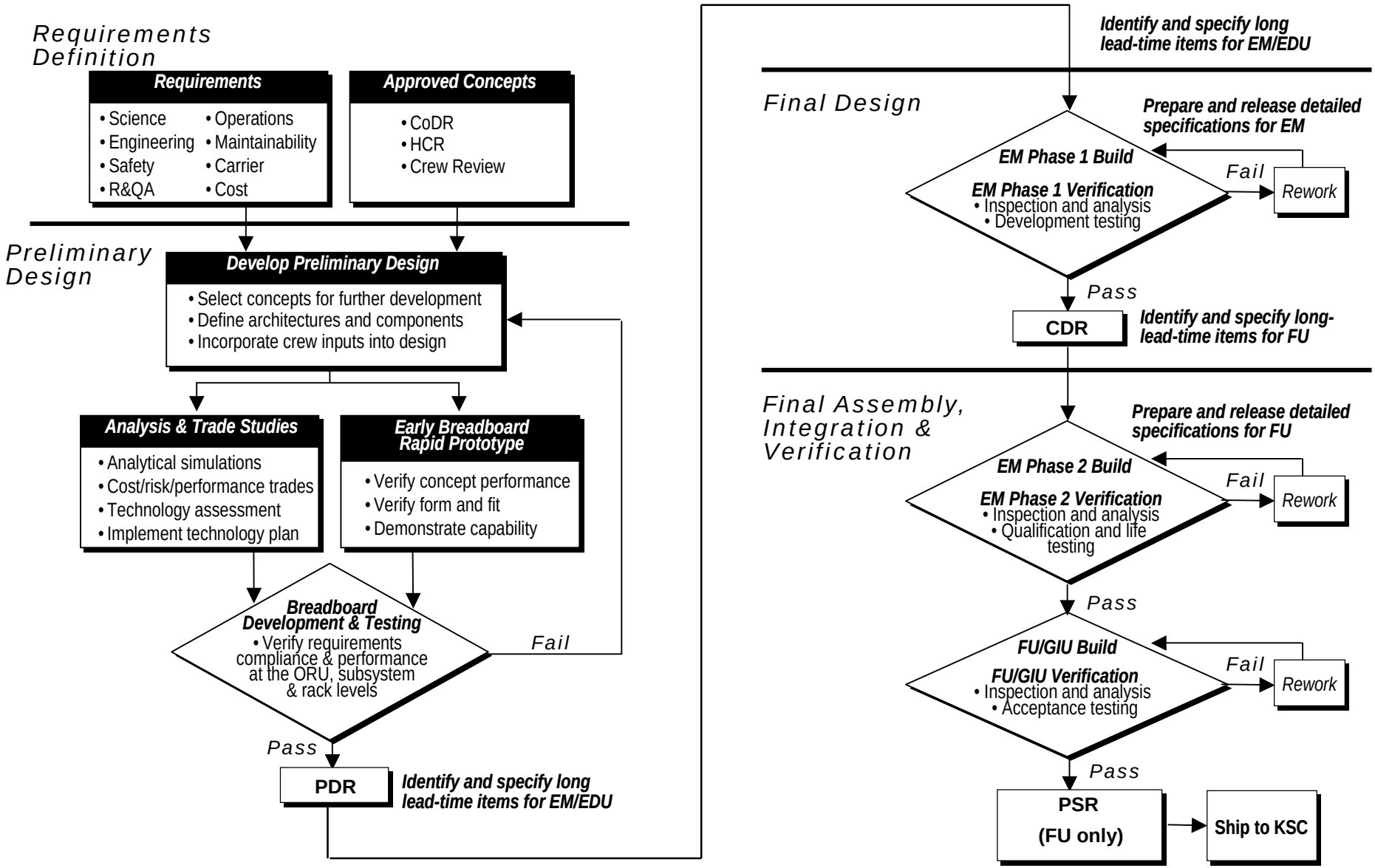
- Ground Integration Unit
- Experiment Development Unit
- PTC Training Unit
- Ground Handling & Testing Equipment
- FCF-Unique Telescience Equipment
- Operations Phase Processes



FCF System

- Development Approach
- Design Drivers
- Design Philosophy
- System Design Features
- System Description

FCF Development Approach



Key constraints that drive the FCF design

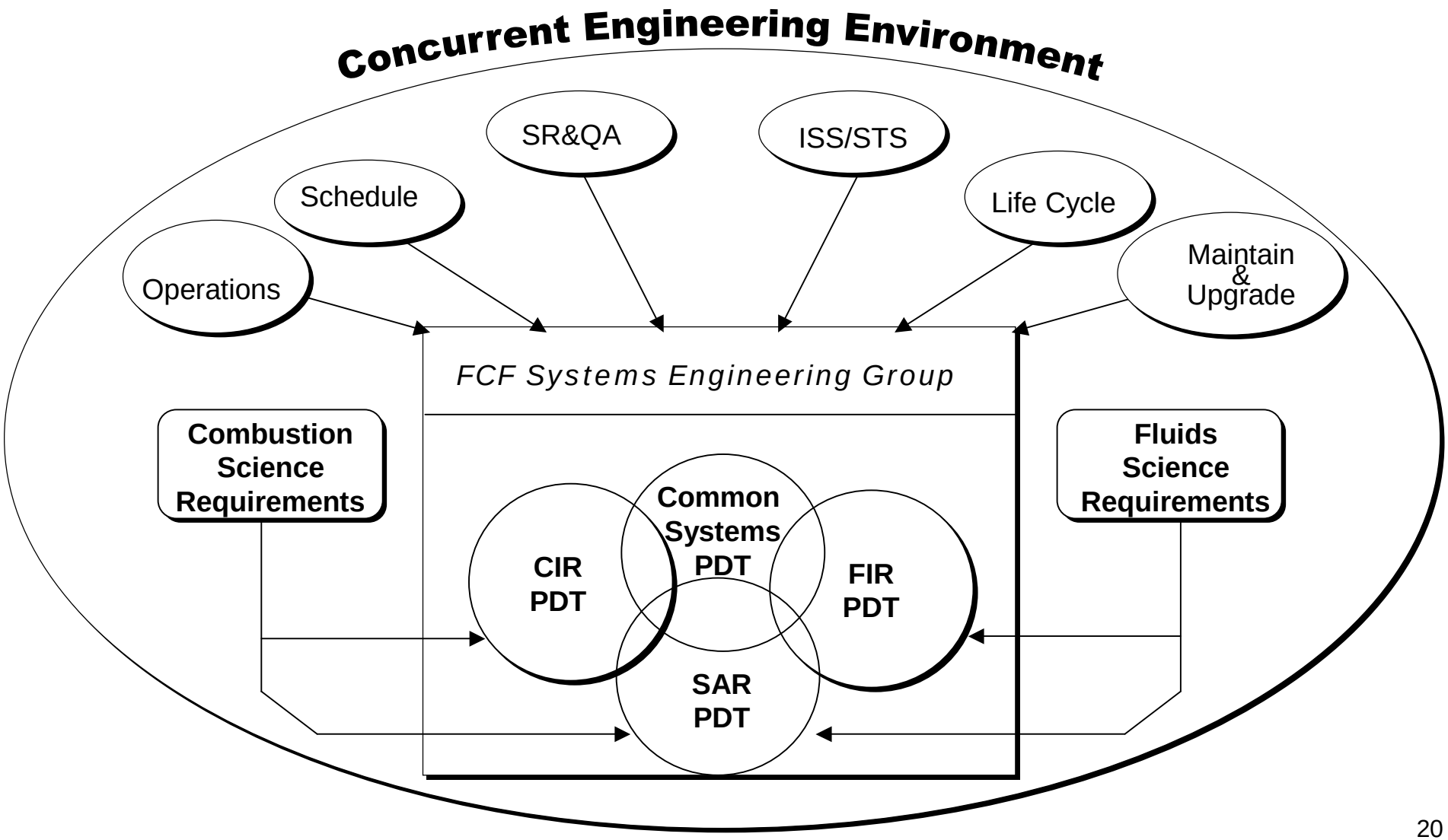
- Rack Mass – limited by launch and on-orbit requirements
- Volume – limited to three contiguous racks plus one rack for stowage
- Power – limited by project requirements and ISS power resources
- Energy - limited by project requirements and ISS power resources
- Crew Time – limited amount of crew time and overall time to perform the FCF mission
- Number of Microgravity days
- Upmass - limited number of flights to ISS and limited upmass for PI and FCF hardware on each flight
- Data Communication – limited bandwidth for downlink of experiment data
- Stowage - limited stowage for on-orbit spares

FCF Specification Key Requirements

- Throughput - 5 combustion and 5 fluids typical basis experiments per year within the following resource constraints:
  - Power - 2000 W
  - Energy - 9000 kW-hrs
  - Thermal Cooling Water - 90 kg/hr
  - Data - 6 Mb/sec, 20 GB/day downlink
  - Crew time - 145 hrs/year
- Provide microgravity environment per experiment requirements
- Average Cost/PI - $ 3.3M in 2005 US dollars
- 10-15 year on-orbit life
- Accommodation of first 6 real experiments
- Ability of three racks to operate as a three rack system

Delivering the required science capability while working within the many constraints and requirements levied on the FCF is accomplished using rigorous systems engineering in a Concurrent Engineering environment.

FCF Concurrent Engineering Approach



FCF Design Philosophy

1) Design for highly automated operation

2) Maximize commonality across all three racks

3) Implement modular design

4) Employ design features for ease of operation, reconfiguration, maintenance and upgrade

5) Maximize use of COTS hardware and software wherever practical

FCF Design Philosophy

1) Design for highly automated operation

FCF hardware and software is designed for automated operation from the ground once the crew has completed the experiment set up.

- Provides greater flexibility for science operations by the PI
  - revision of experiment timeline to react to unexpected science phenomena
  - rerun test points that require a second look
- Dramatic reduction in crew time required to complete experiment test matrix

FCF Design Philosophy

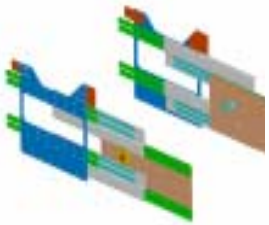
2) Maximize commonality across all three racks

Maximizing commonality across all three racks and between subsystems reduces program risk while optimizing for the fluids and combustion missions.

- Reduces common hardware, software, test methods, inspections, assembly and test procedures, materials, etc. improves repeatability and product quality
- Common operational procedures reduce risk of crew confusion
- Reduces total number of analyses, tests, and designs
- Reduces total life cycle costs
- Allows common sparing on orbit

FCF Common Hardware

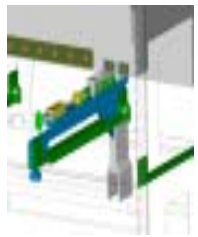
Structural



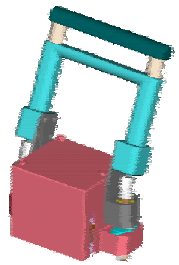
Slides

Rack Door

Left and Right
Pin Assembly

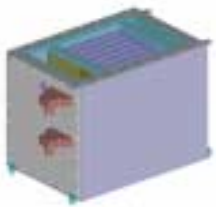


Center
Post

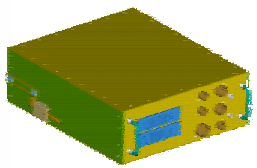


Removable Latch Mount

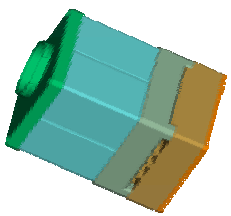
Command and Data



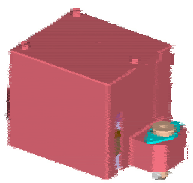
IPSU



IOP

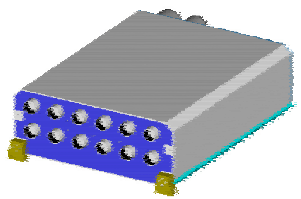


IAM



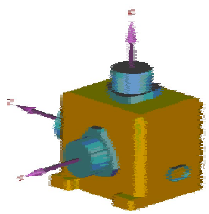
DCM

GFE



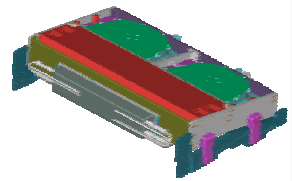
EPCU

ARIS and ISPR



SAMS FF

ECS



ATCU with ATCU Rack
Attachment Hardware

GIS

WTCS

FDSS

FCF Design Philosophy

2) Implement modular design

Modular design of hardware and software:

- Allows interchange of Orbital Replacement Units (ORUs) between racks, increasing system flexibility and reducing stowage needs
- Reduces crew time
- Aids in sparing
- Provides for fault isolation
- Accommodates new ORU upgrades or new PI hardware and software
- Modular software approach uses latest development tools/techniques, object oriented analysis, and design philosophy to maximize commonality, reusability and maintainability.

FCF Design Philosophy

3) Employ design features for ease of operation, reconfiguration, maintenance and upgrade. Examples include:

- 1/4 turn captive fasteners
- quick disconnects for fluid lines
- C-mount adapters for diagnostic packages
- one handed package change out using quick latch device
- waffle plate bench with quick thumb latch hold down in FIR and SAR

Modular design of packages along with quick latch device provides fast, easy reconfiguration of the bench.

FCF Design Philosophy

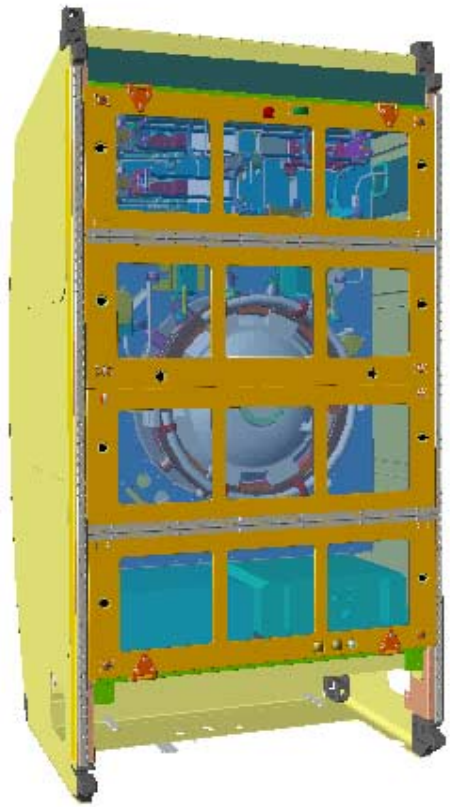
4) Maximize use of COTS hardware and software wherever practical to reduce life cycle costs and provide readily available upgrade paths. Examples include:

- processor boards and disk drives
- diagnostic elements (cameras, lenses, etc.)
- VxWorks operating system
- fluid supply bottles
- gas chromatograph
- others

FCF Design Feature: Deployable Optics Bench

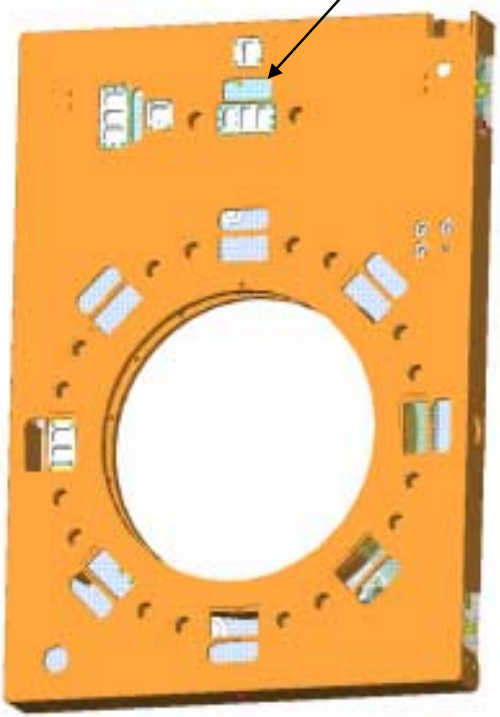
Deployable optics bench:

- Allows crew easy access to both front and back of bench
- Minimizes time required to reconfigure rack between experiments

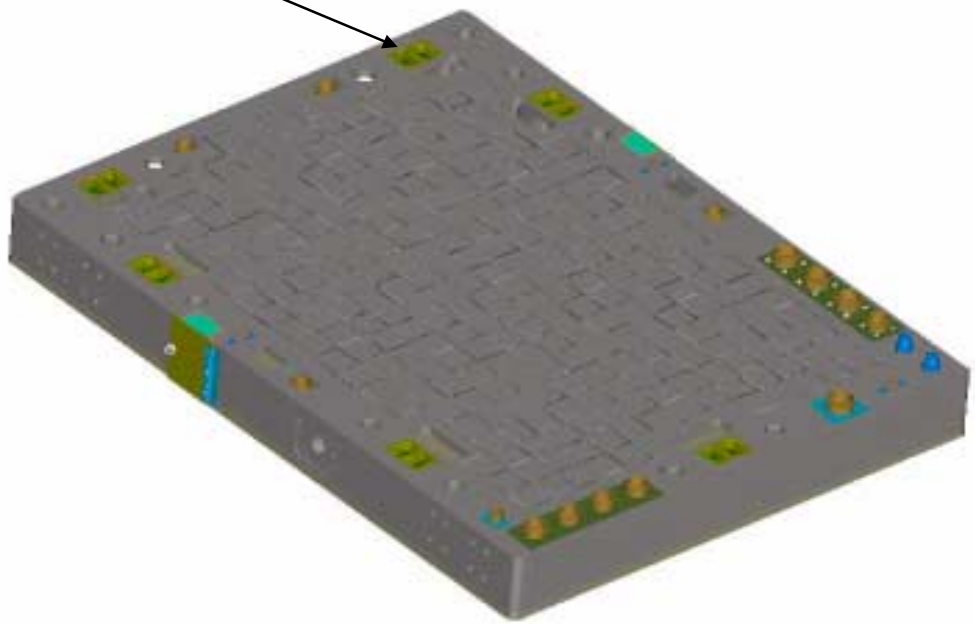


FCF Design Feature: Commonality between Optics Bench designs

Cooling, Power, Data and Mechanical Interfaces allow for interchangeability of packages between racks.



CIR Optics Bench

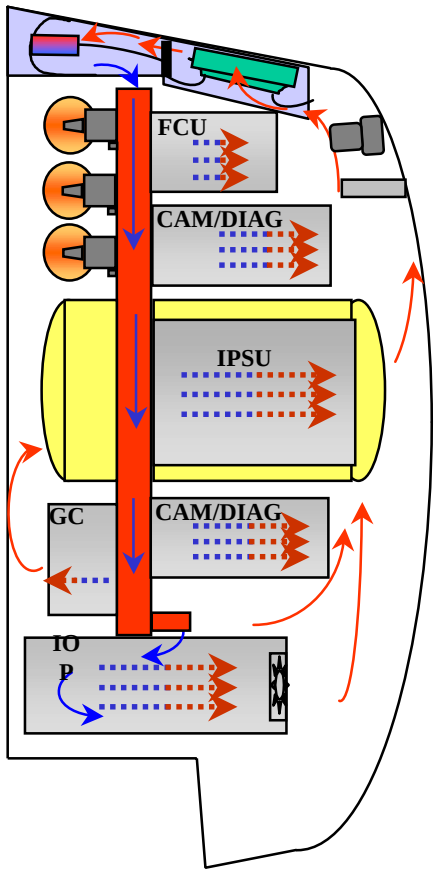


FIR & SAR Optics Bench

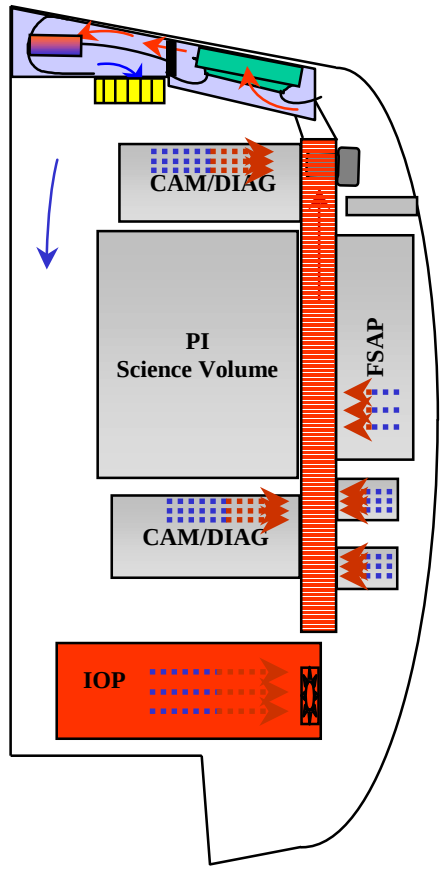
FCF Design Feature: Ducted Bench Cooling

Ducted bench cooling:

- Provides ease for PI design from a thermal standpoint
- Better control of ATCU exit air
- Reduces number of fans and other components that are potential noise and microgravity disturbance generators



CIR uses positive pressure

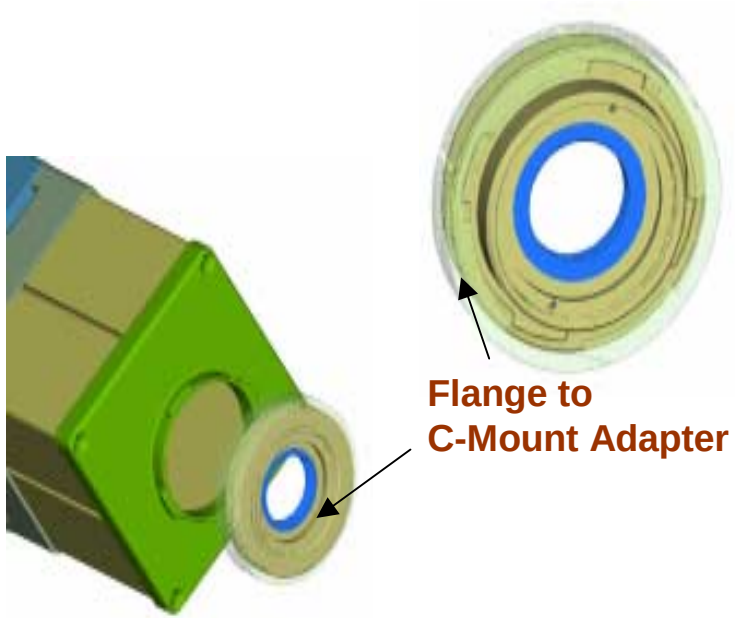


FIR and SAR use negative pressure

FCF Design Feature: No Tools Required for Reconfiguration

Standard connections for components and packages results in reconfiguration between experiments:

- Simplifies crew procedures
- Enhances ability to use between racks
- Minimizes stowage
- Reduces crew time required for reconfiguration between experiments

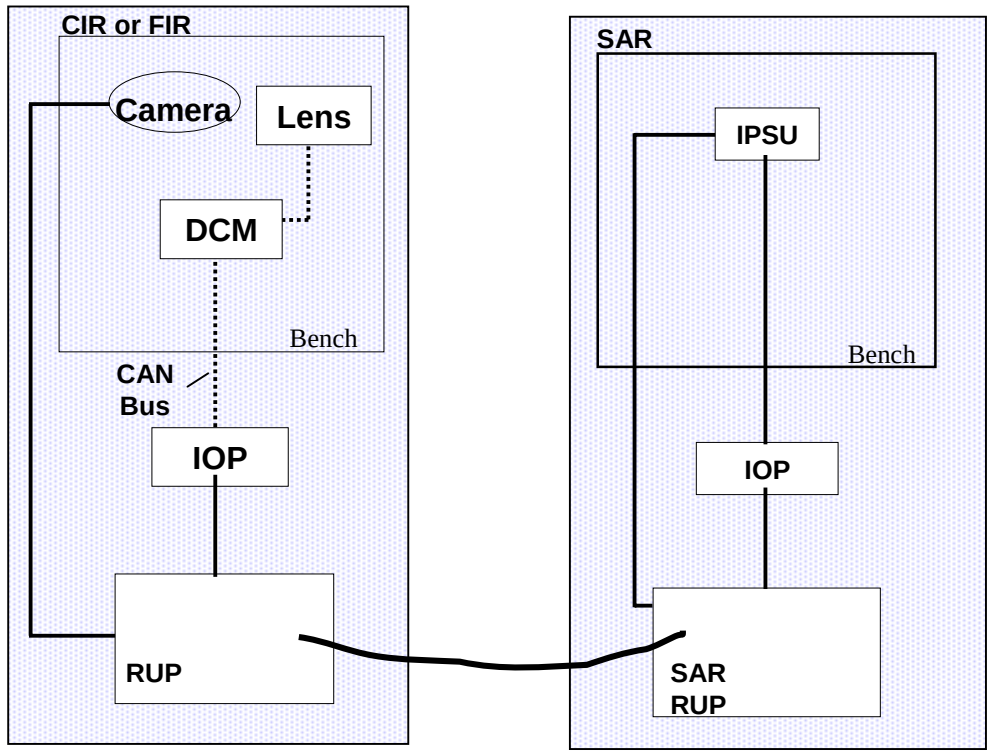


IAM Four Flange Mount Interface

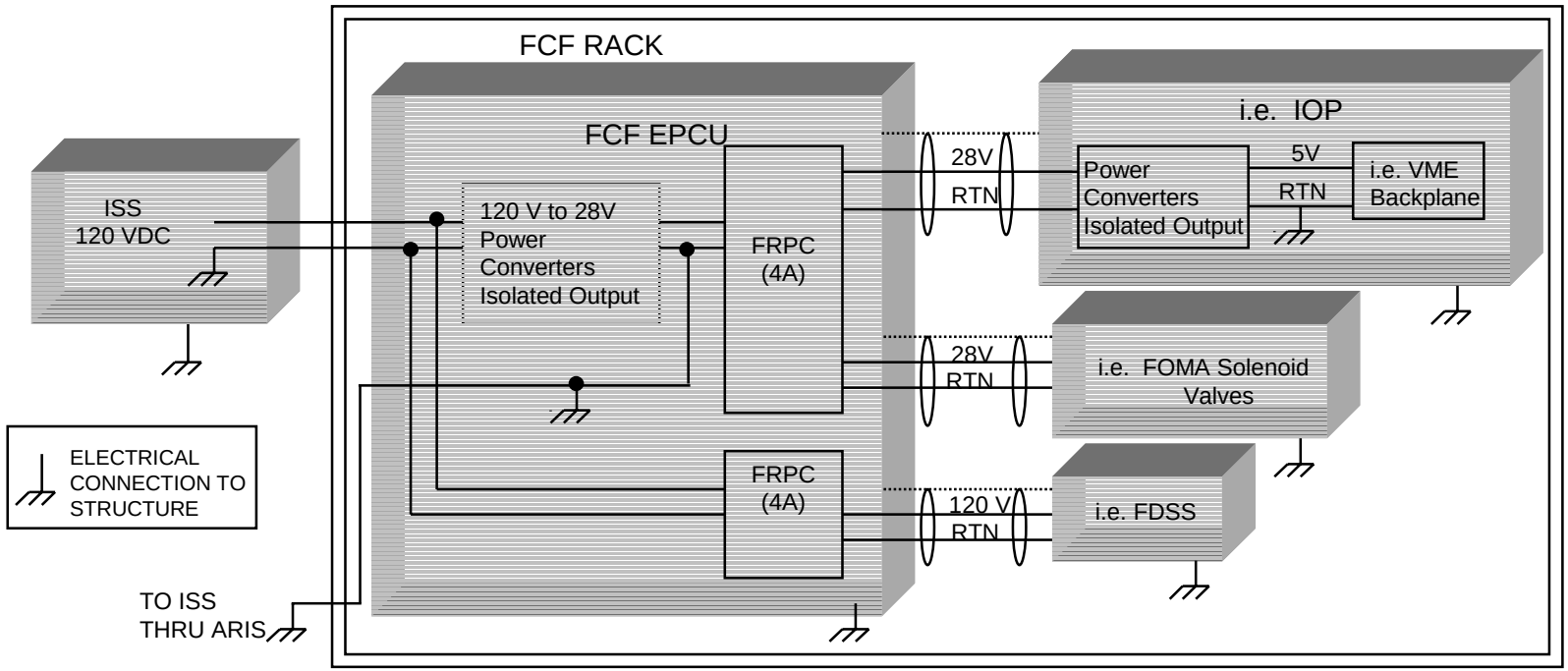
FCF Design Feature:Rack to Rack Communication

Communication between racks:

- Allows better use of resources
  - Offloading of mass
  - Space for additional diagnostics
- Allows for centralized control of all three racks

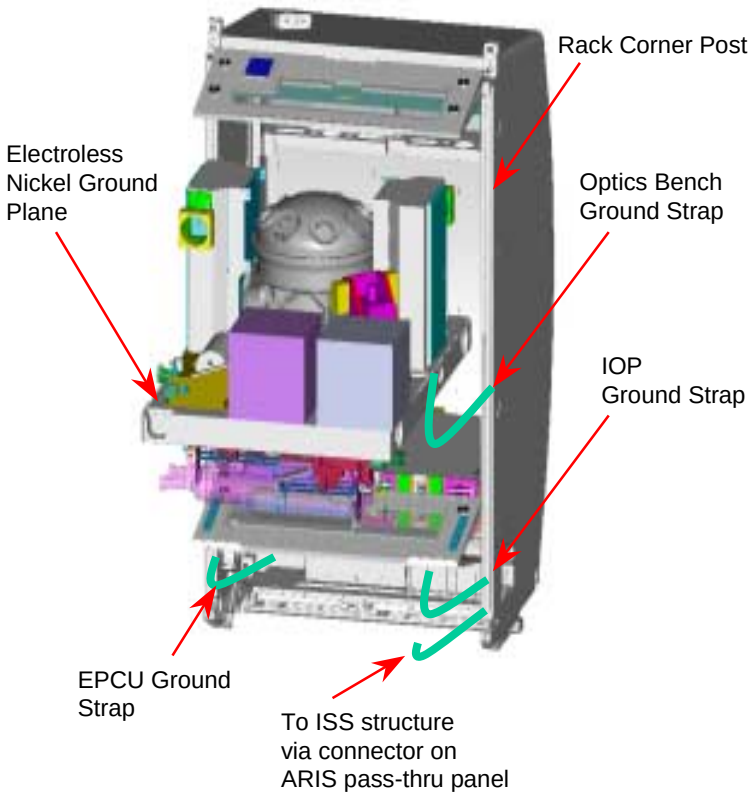


FCF Design Feature: Rack Electrical Grounding



- ISS Secondary power isolated from chassis
- Separately derived electrical power source connected to structure at no more than one point
- Package-to-package communication designed to eliminate ground loops utilizing fiber optics or isolated differential signals
- Wiring and cabling shall meet applicable requirements specified in SSP 30242,ISS Cable/Wire Design and Control Requirements for Electromagnetic Compatibility
- System grounding shall meet applicable requirements specified in SSP 30240, ISS Grounding Requirements

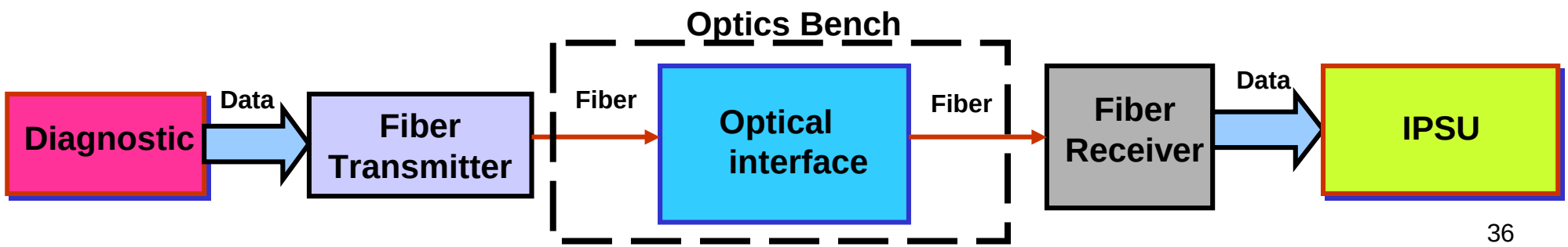
FCF Design Feature: Rack Bonding



- Entire optics bench mounting surface shall be electroless nickel.
- Diagnostic package mounting surface to optics bench shall be electroless nickel.
- ARINC optics bench and diagnostic package connectors surface material shall be electroless nickel.
- Bonding strap shall be used to establish an electrical bond between the optics bench and rack per SSP 30245.
- Bonding straps shall be attached to the nickel-plated mounting locations provided on the rack corner post.
- On-orbit bond reverification of interchangeable optics bench packages will be accomplished via a visual inspection of the mating surfaces. Bonding is accomplished through mounting surfaces of the diagnostics package and the optics bench. A secondary path is through the connector shell.
- Packages separate from the optics bench such as the EPCU and IOP will utilize bonding straps attached to the rack corner post.

FCF Design Feature: Fiber Optic Serial Data Link (SDL)

- SDL converts parallel data lines from diagnostic packages onto a very-high speed optical transmission medium. At the receiving end the data is restored to a parallel format for processing.
- Using the SDL greatly reduces the number of conductors in each rack and allows rack to rack communications.
- Fiber optic line is very immune to any noise interference and does not radiate any electrical noise.
- PI provided digital cameras may require customization of SDL at the camera interface.



FCF System

Each rack has stand alone capabilities

- CIR will be able to conduct combustion experiments.
- FIR will be able to conduct fluids experiments.
- SAR will be able to conduct fluids experiments, combustion experiments (if required containment vessel is provided by PI), and middeck experiments.

The integrated system has enhanced capabilities

- Augment FIR capabilities with SAR in order to conduct range of fluids experiments that cannot be fully accomplished by the FIR alone.
- Augment CIR capabilities with SAR in order to conduct range of combustion experiments that cannot be fully accomplished by the CIR alone.
- Improve FIR and CIR efficiency by SAR processing data and down linking previous run while experiments continue in FIR or CIR. This will allow for more science to be performed.

FCF System

Benefits of the Integrated FCF system

SAR completes the FCF system

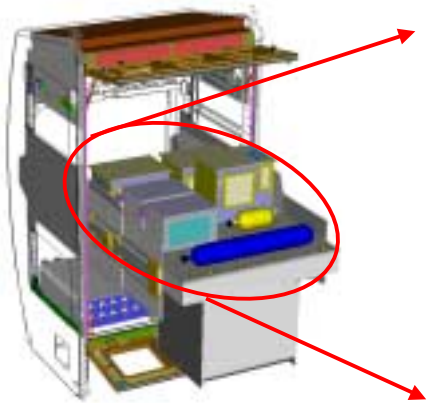
•Provides flexibility to off-load hardware from optics plates in CIR and FIR to create additional space for PI-specific equipment, enhancing science data return.

- CIR - opportunity to view into chamber from all 8 window locations
- FIR - enables simultaneous operation of high-resolution, high frame rate diagnostics

•Capability to provide additional data storage in the SAR allows for greater number of test runs that would otherwise be precluded by ISS downlink limitations and/or a single rack's data storage capability.

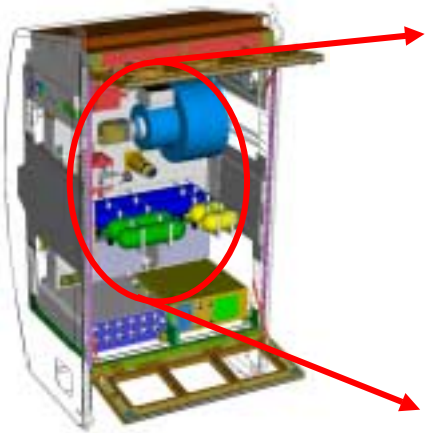
•Allows for experiments that would otherwise exceed a single rack's limit for mass, volume or cooling capability.

The SAR Permits FCF to Operate at Full Performance



Advanced FCF Data Handling - *Completes FCF Imaging/Data Capabilities*

- **Input/Output Processor** for facility command, control, health and status monitoring
- **Image Processing Storage Units (2)** for combustion and fluids image acquisition, processing, storage
- **Additional Data Processing Capability** for processing data from multiple experiments
- **Mass Storage** of FCF Science Data with removable media for return to Earth
- **Video Monitor** for crew interface
- **SAR Science Avionics Package** for experiment data handling.
- **Imaging Interface** for other US Lab science rack usage.



Additional FCF Science Accommodations - *Science Support and Throughput*

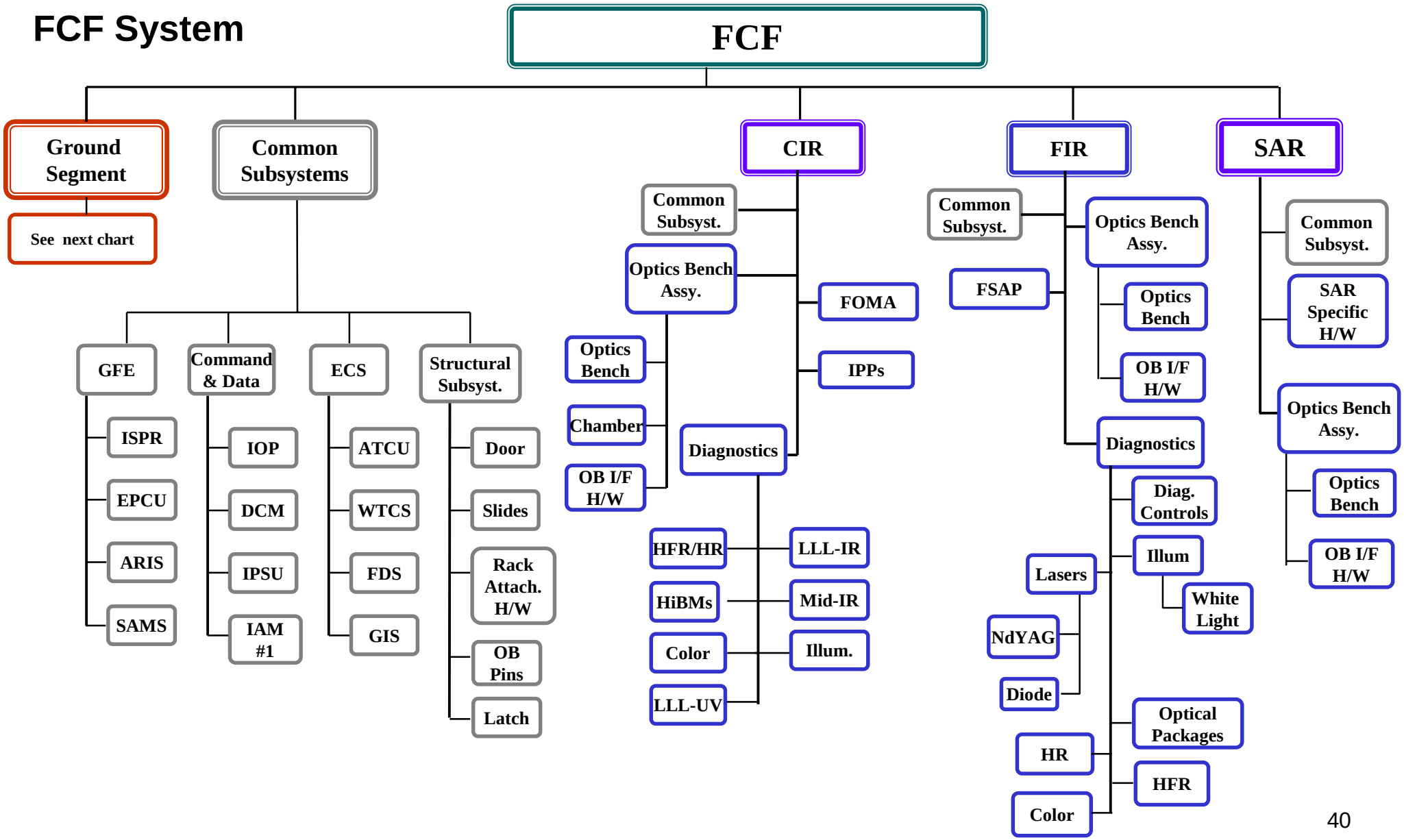
- **Science Optics Bench** for hardware mounting, servicing and access, as well as experiment accommodation
- **Science Sample Conditioning** (e.g., powered fluid sample preparation and storage)
- **Mid-deck Locker Interface** with avionics simulators and interfaces

Potential for FCF Upgrades – *Enhanced Capabilities Possible after SAR Deployment*

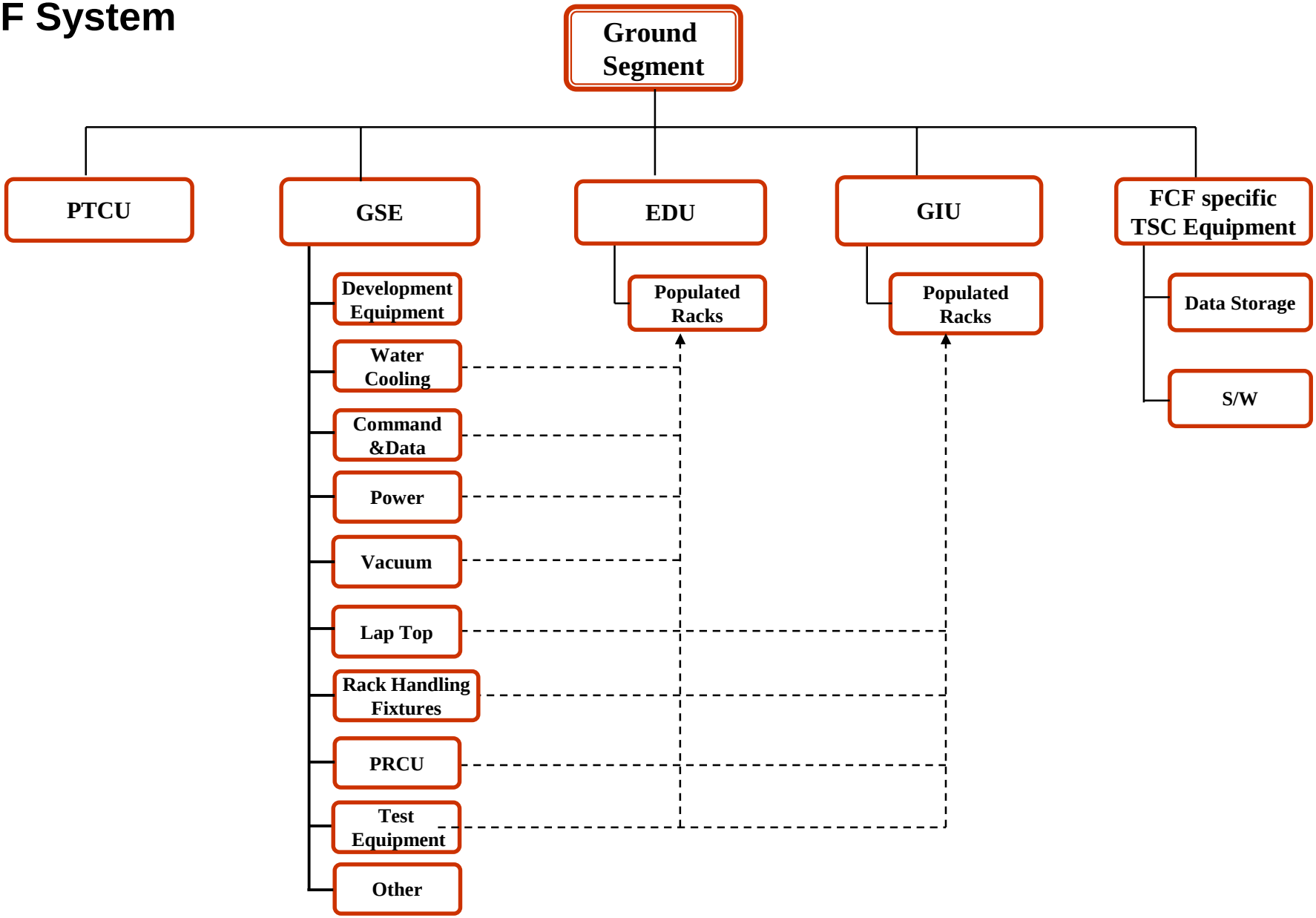
- **Calibration Apparatus** for FCF equipment requiring regular on-orbit calibration.
- **On-Orbit Logistical Equipment** to maximize system readiness & throughput
- **FCF Diagnostic Compatibility** with CIR and FIR diagnostics to support SAR science payloads
- **Multiple PI-Specific Hardware** available on-orbit at all times to maximize flexibility and thru-put
- **Gas/Fluid Supply** to support CIR/FIR science
- **Chemical Analysis Capability** for on-orbit fluid sampling and analysis (e.g., mass spectrometer)

The FCF Shared Accommodations Rack (SAR) provides centralized command & data handling capability and multipurpose science volume needed to maximize FCF system effectiveness and meet fluids and combustion science requirements.

FCF System

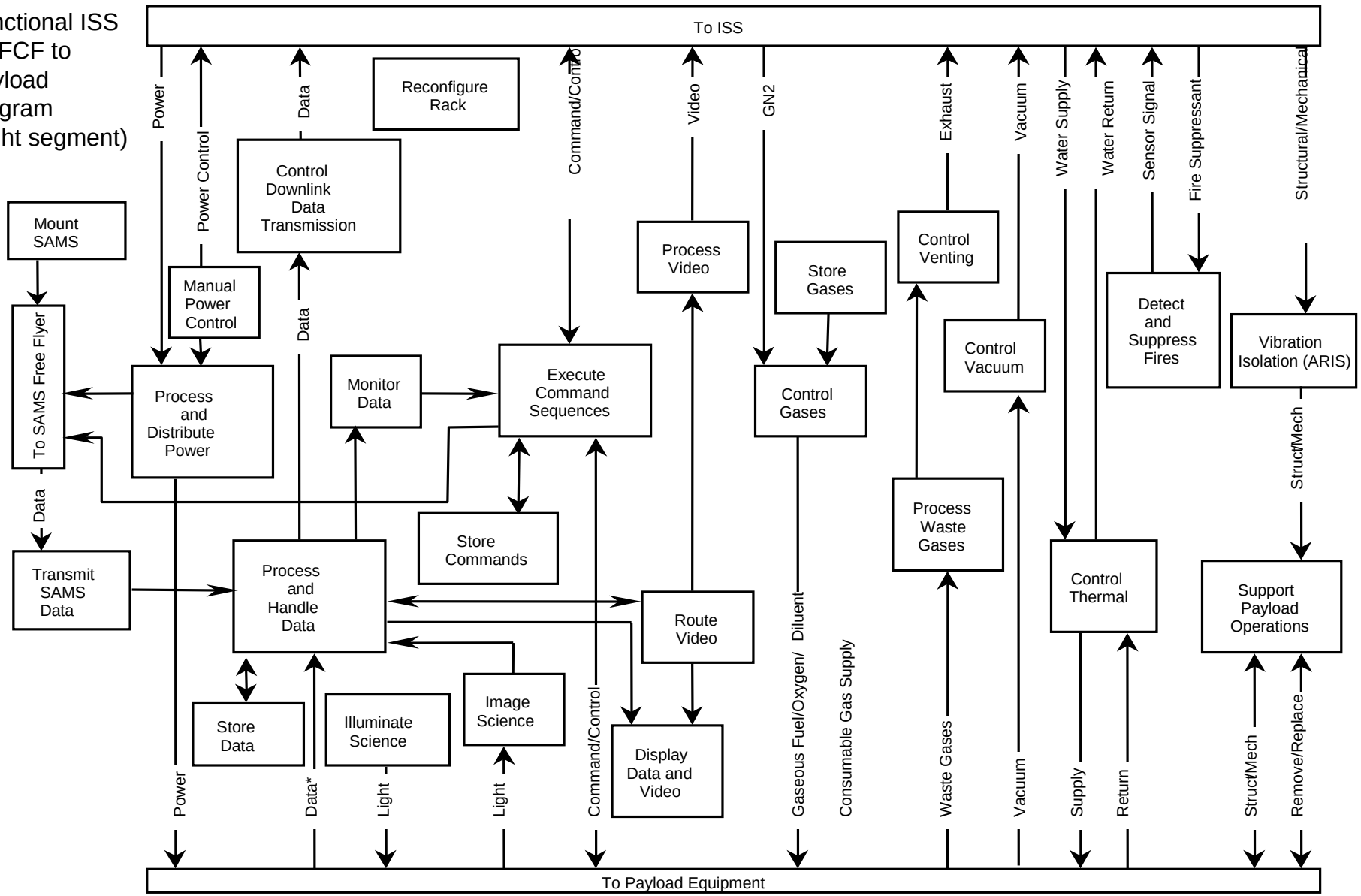

FCF
Ground Segment
See next chart
Common Subsystems
GFE
ISPR
EPCU
ARIS
SAMS
Command & Data
IOP
DCM
IPSU
IAM #1
ECS
ATCU
WTCS
FDS
GIS
Structural Subsyst.
Door
Slides
Rack Attach. H/W
OB Pins
Latch
CIR
Common Subsyst.
Optics Bench Assy.
Optics Bench
Chamber
OB I/F H/W
FOMA
IPPs
Diagnostics
HFR/HR
HiBMs
Color
LLL-UV
LLL-IR
Mid-IR
Illum.
FIR
Common Subsyst.
FSAP
Optics Bench Assy.
Optics Bench
OB I/F H/W
Diagnostics
Diag. Controls
Illum
White Light
Lasers
NdYAG
Diode
Optical Packages
HR
HFR
Color
SAR
Common Subsyst.
SAR Specific H/W
Optics Bench Assy.
Optics Bench
OB I/F H/W

FCF System


Ground Segment
PTCU
GSE
EDU
GIU
FCF specific TSC Equipment
Development Equipment
Water Cooling
Command &Data
Power
Vacuum
Lap Top
Rack Handling Fixtures
PRCU
Test Equipment
Other
Populated Racks
Populated Racks
Data Storage
S/W

FCF System: Interfaces

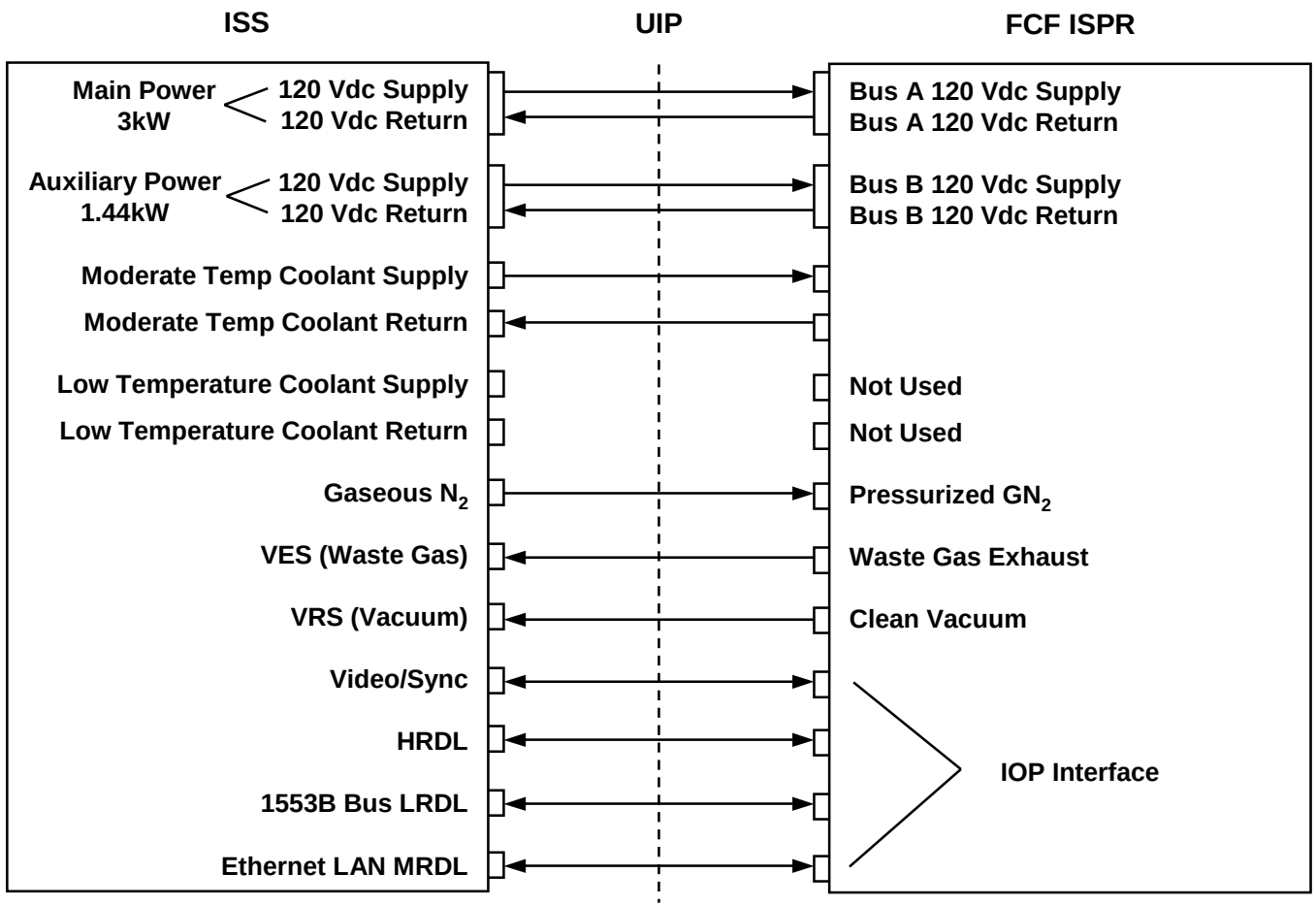
Functional ISS To FCF to Payload Diagram (flight segment)



* - including analog & digital video

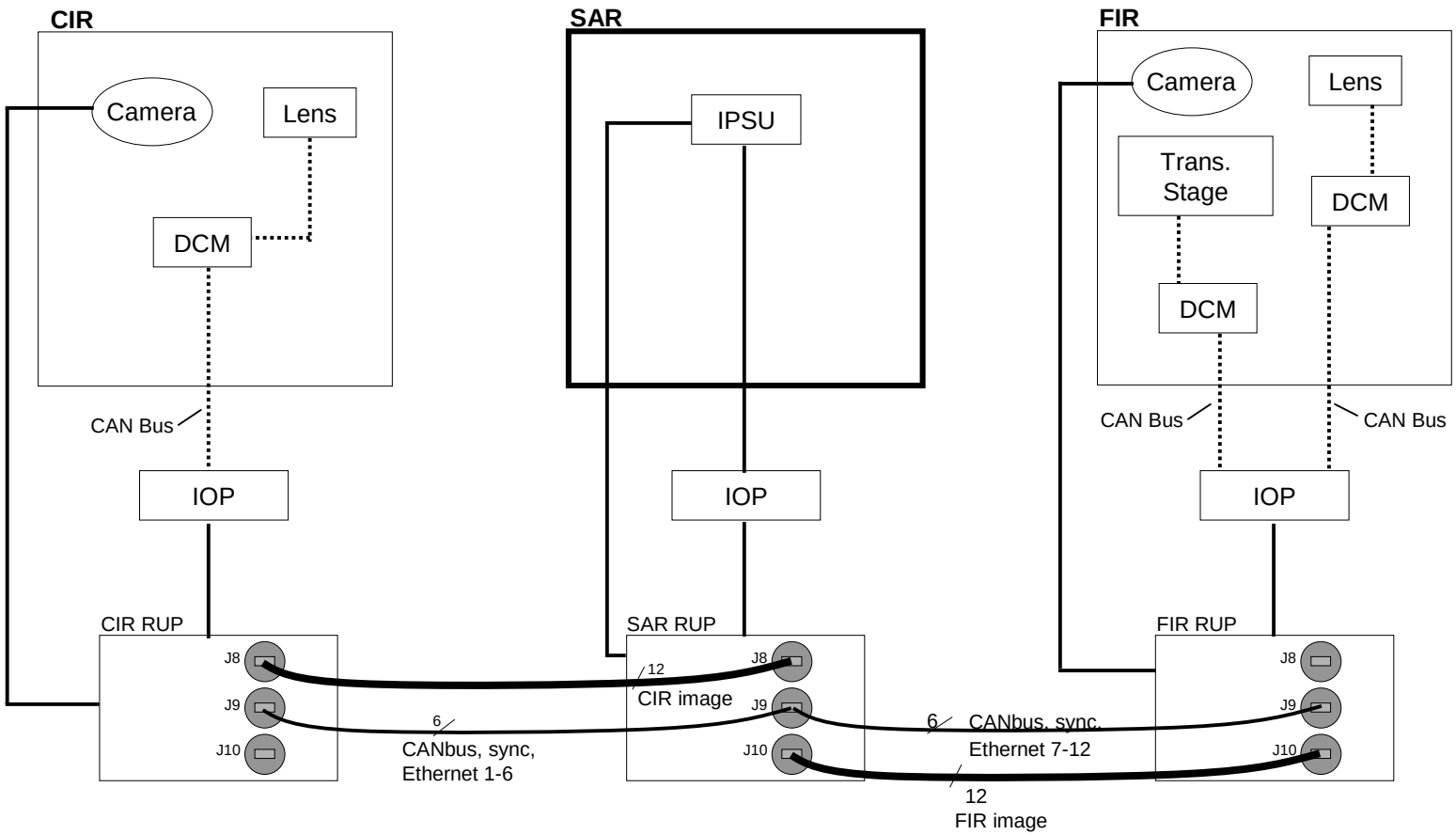
FCF System: Interfaces

ISS to Rack Interfaces through UIP



FCF System: Interfaces

FCF Electrical System: Rack to Rack Interface

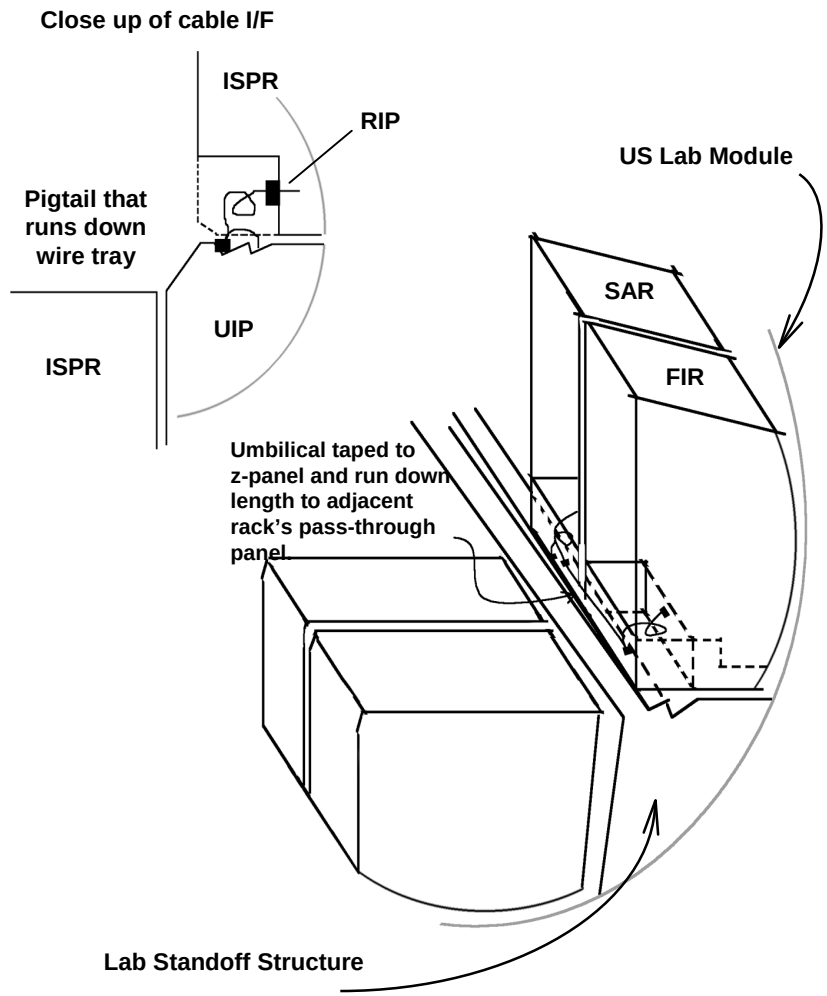


FCF System: Interfaces

FCF Electrical System: Rack to Rack Interface

Rack to Rack Umbilical Concept

- ✓ Fiber optic cable bundle routed from SAR to each science rack along z-panel.
- ✓ Connectors added to ARIS pass through panel at each rack.
- ✓ FCF diagnostic capabilities are accessible to non-FCF payloads via connectors on SAR, CIR, FIR pass-through panels.
- ✓ Allows high-speed data transfer between racks independent of ISS C & DH system.

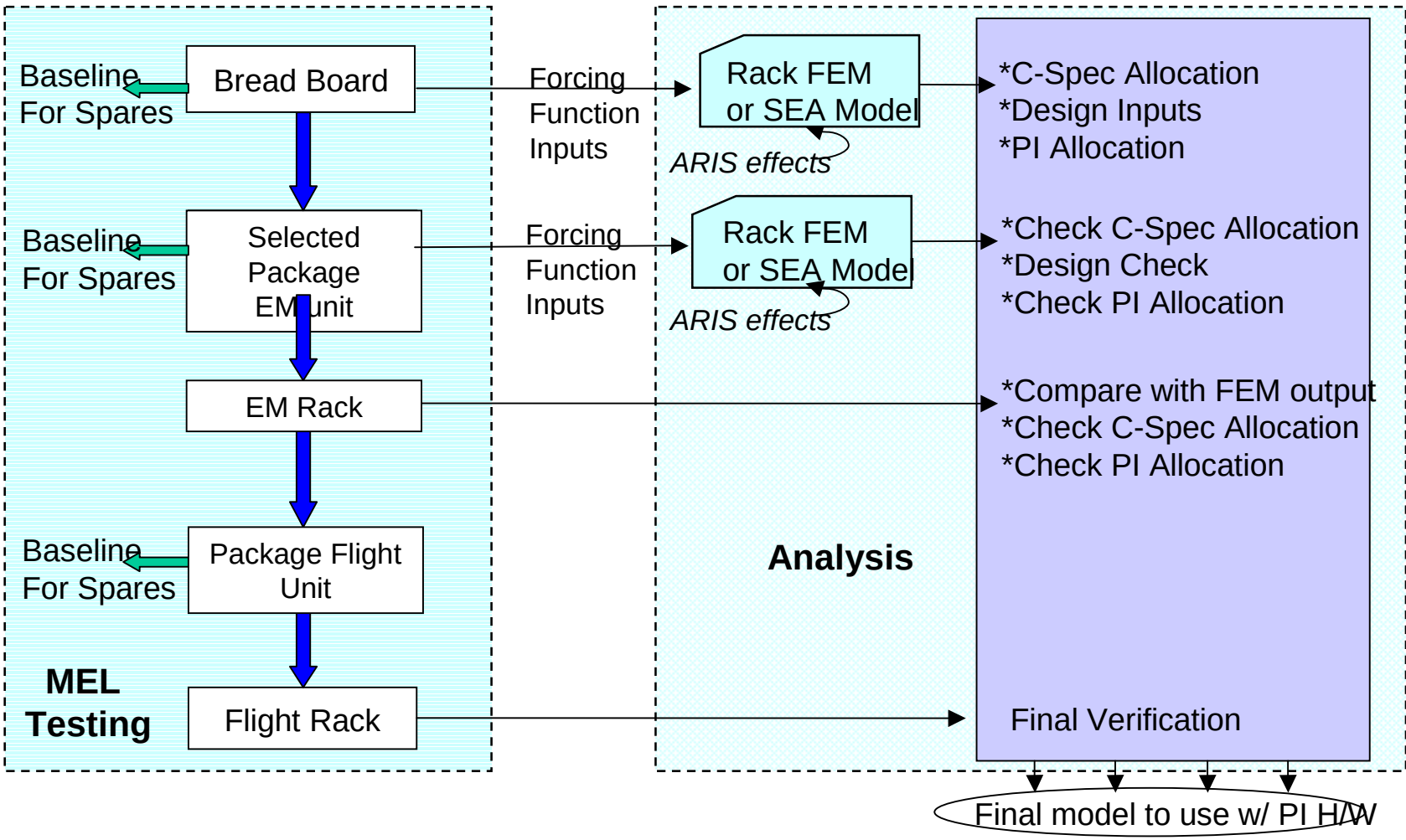


Analysis Approach and Processes

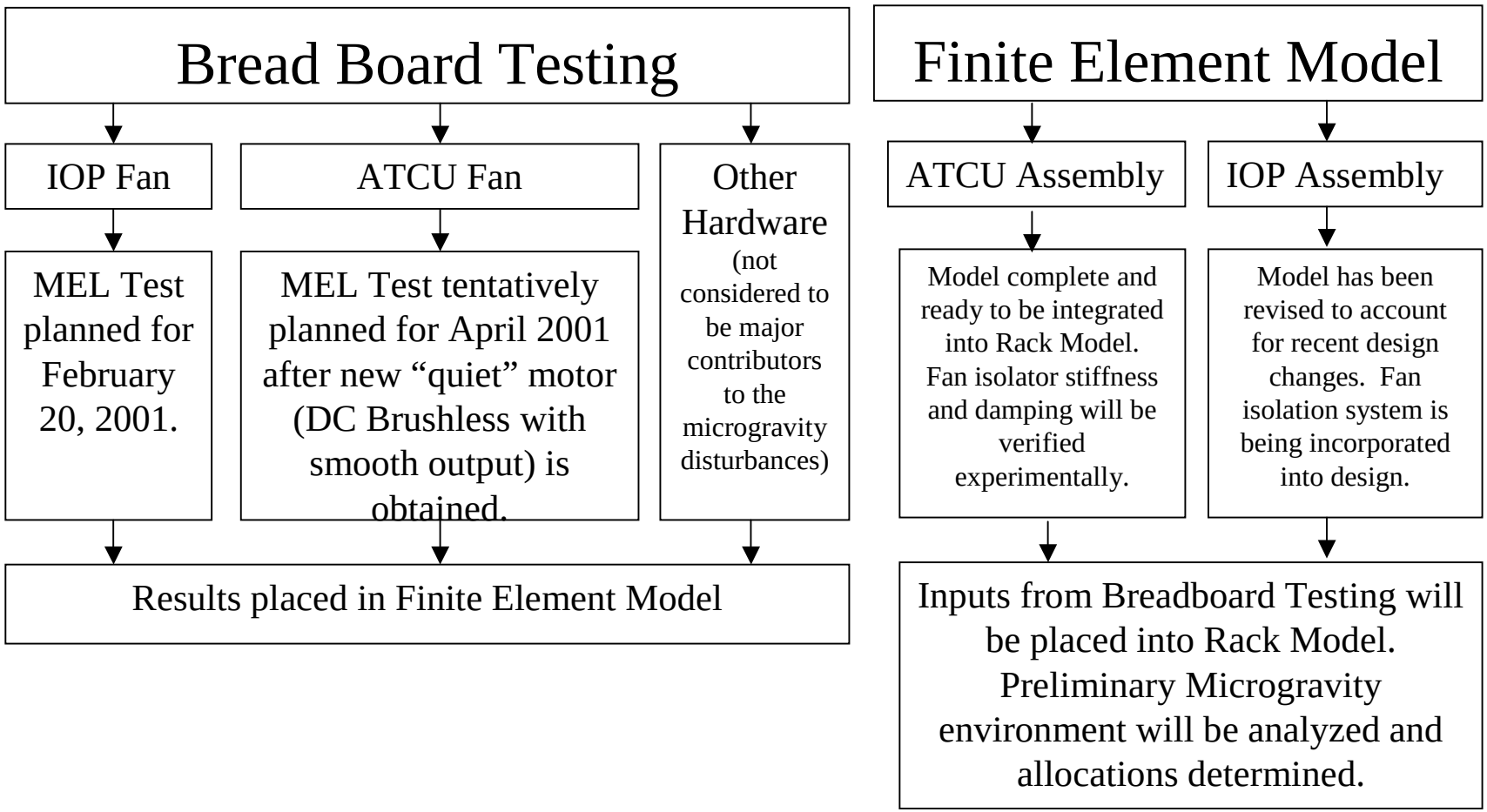
Analysis and Test Approach

- Major system approaches have been described for each of the major flight environments in plans that integrate the analysis and testing for the following critical areas:
  - Microgravity Control
  - Acoustic Noise Control
  - Thermal Analysis and Test
  - Structural Analysis and Vibration Testing
  - EMI Compatibility

Microgravity Control Approach



Microgravity Verification – Current Status



Acoustic Noise Control Approach

Initial Process

Noise requirements set by SSP 57000 Revision E

Make initial assessment of component contribution. Section 4.0

Make initial assessment of integrated rack noise levels. Section 4.0

Determine component levels needed for rack compliance. Section 4.0

Modify design to meet requirement. Section 5.0

Final Process

Baseline Design

Perform acoustic test to verify compliance. Section 6.1

Redesign

Fail

Final design

Compliance

Perform integrated acoustical test for the rack. Section 6.2

Pass

Verification Complete

Non-Compliance

Perform diagnostic tests to identify noise sources and path. Section 7.0

Investigate noise attenuation techniques. Section 7.0

Perform acoustic analysis and test. Section 7.0

Modify design. Section 7.0

Current level of completion

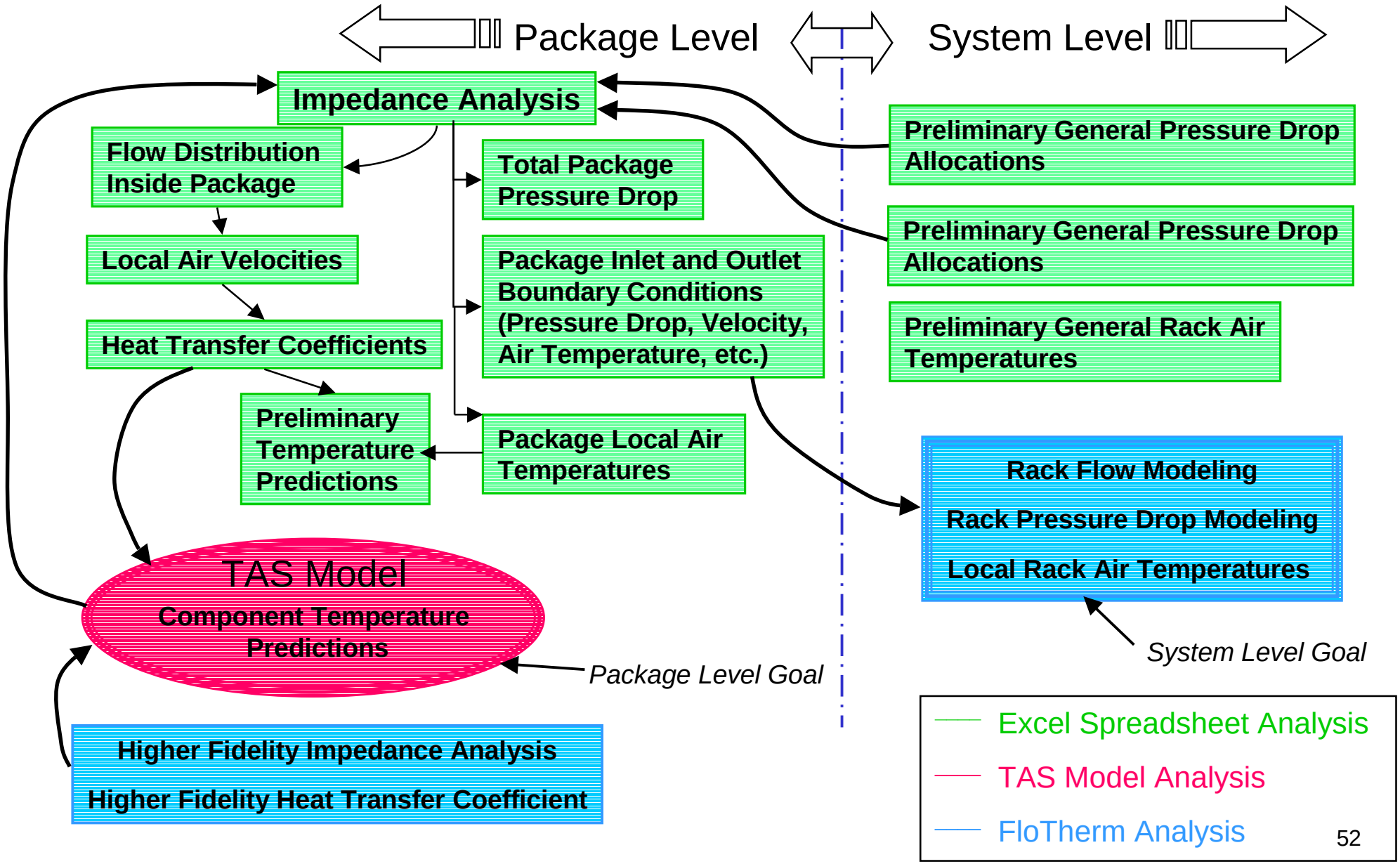
Acoustic Noise Verification - Current Status

Make initial assessment of component contribution.

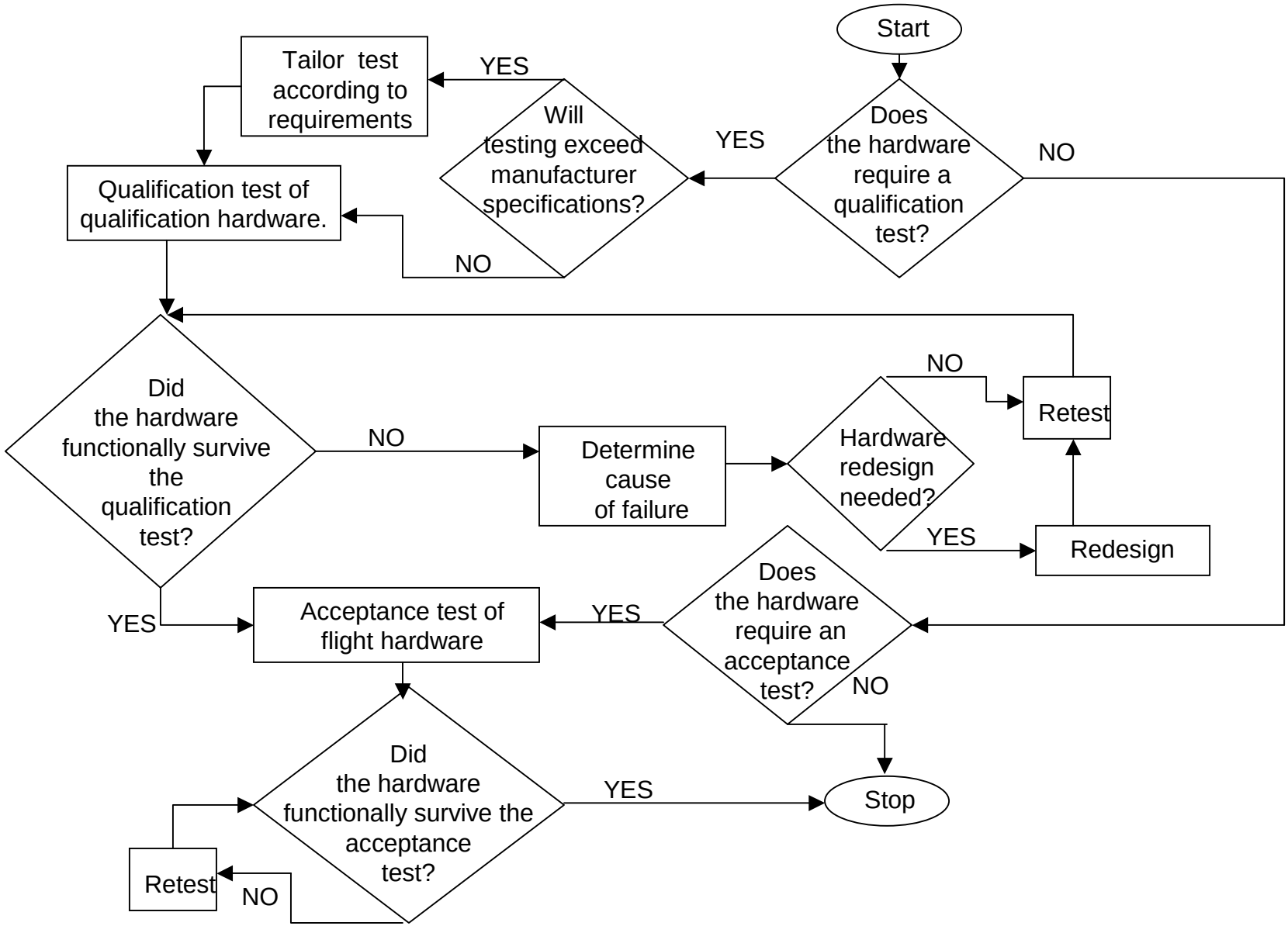
- ATCU Fan
  - New "quiet" motor being researched (DC brushless motor with a smooth output)
- IOP Fans (4 candidate fans tested)
  - Fan with lowest noise level selected for the IOP
    - Analysis of IOP fan noise to determine its contribution to the total noise of an integrated rack on the ISS. Results show that the acoustical noise is below NC-35.
- FOMA Recirculation Pumps
  - Acoustic Testing of modified FOMA pumps mounted on a test fixture and also mounted on the combustion chamber planned for 1-16-01.
    - Analysis of data in progress.
- GC Sampling Pump
  - Acoustic Testing of GC Sampling pumps mounted in the GCIP Package planned for 6-01-01.
- IOP & FCU Hard Drives planned for 03/01/01

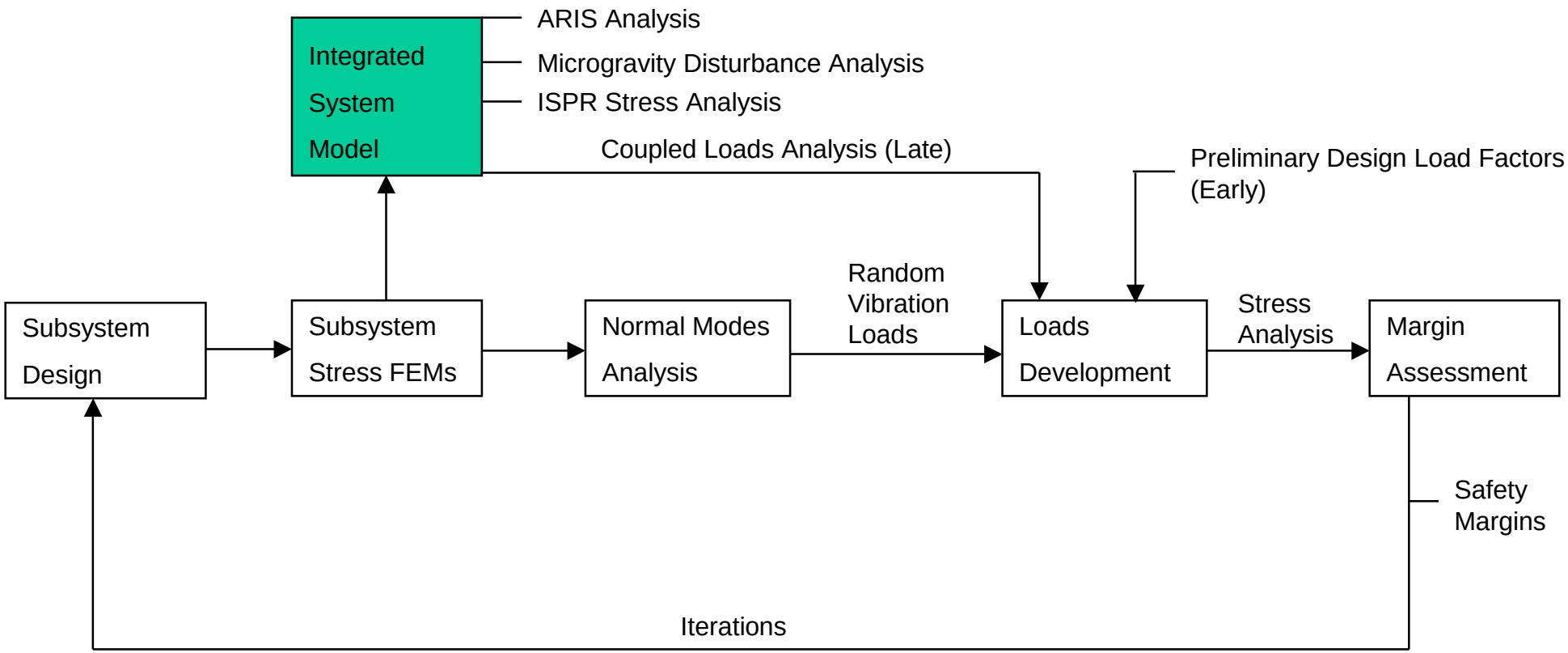
Test Outcome Actions

Thermal Analysis Overview



Thermal test approach





FCF STRUCTURAL ANALYSIS PROCESS

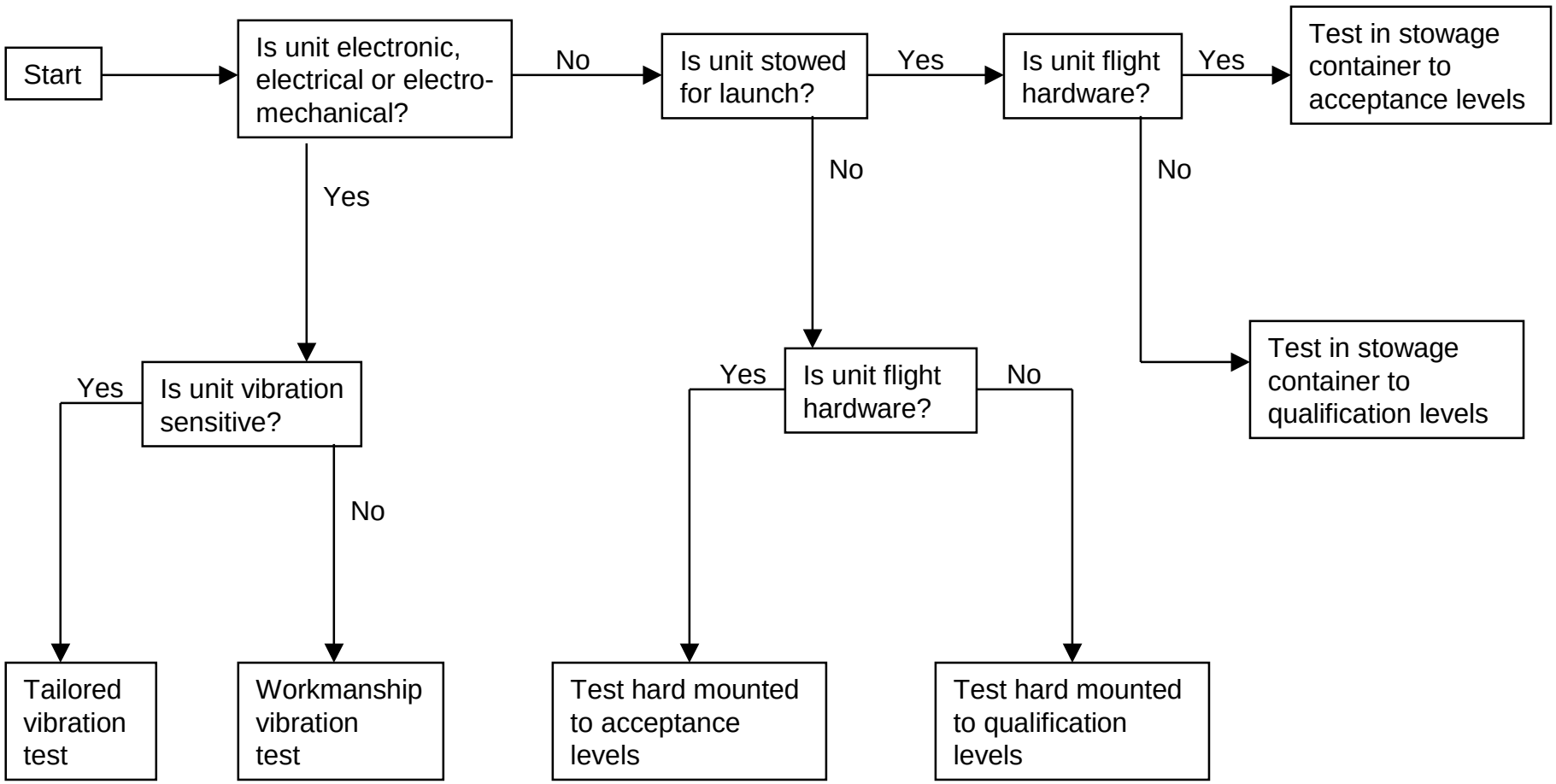
STRUCTURAL ANALYSIS APPROACH

- Flight safety requires analysis of all safety critical structures
- Safety critical structures defined as structure in payload primary load path including pressurized systems
- Requirement met using a combination of classical (hand) and finite element analysis
  - Classical analysis used on fasteners (Chambers approach) and certain parts like FOMA manifolds
  - Finite element models created for each FCF subsystem (Optics Bench Assembly, ATCU, etc.)
- Fracture critical parts assessed using FLAGRO
- Fatigue life assessed using fracture analysis (FLAGRO) – a conservative approach

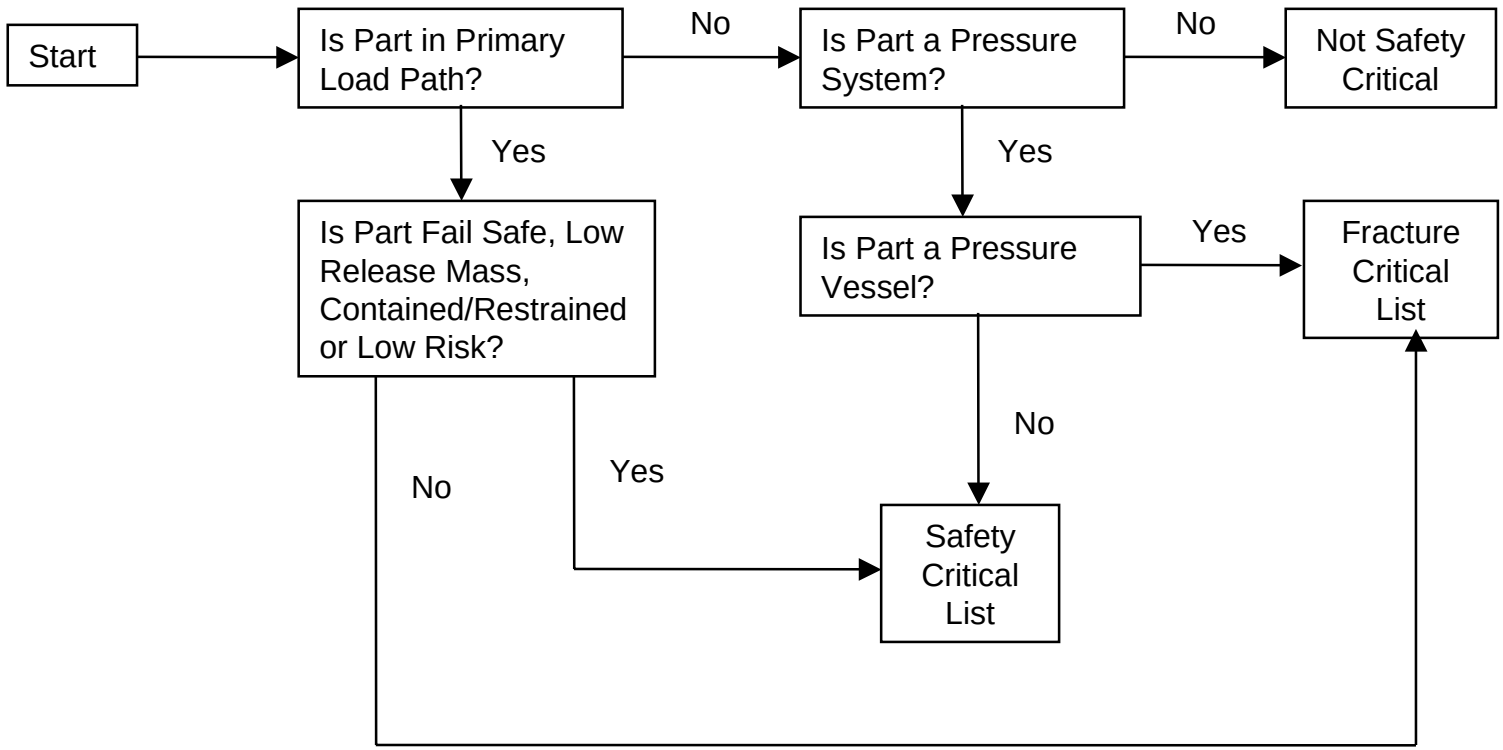
STRUCTURAL ANALYSIS APPROACH (cont.)

- Finite element models integrated into ISPR model for rack level analysis
  - Launch and landing loads stress analysis
  - Launch and landing coupled loads analysis
  - ARIS performance analysis
  - Microgravity disturbance analysis
- Few separate (less detailed) dynamic FE models; stress model fidelity required for higher frequency analysis
- For PDR a summary of results are documented in Safety Critical Structures Data Package
- For CDR a detailed stress report will be written for each major structural element

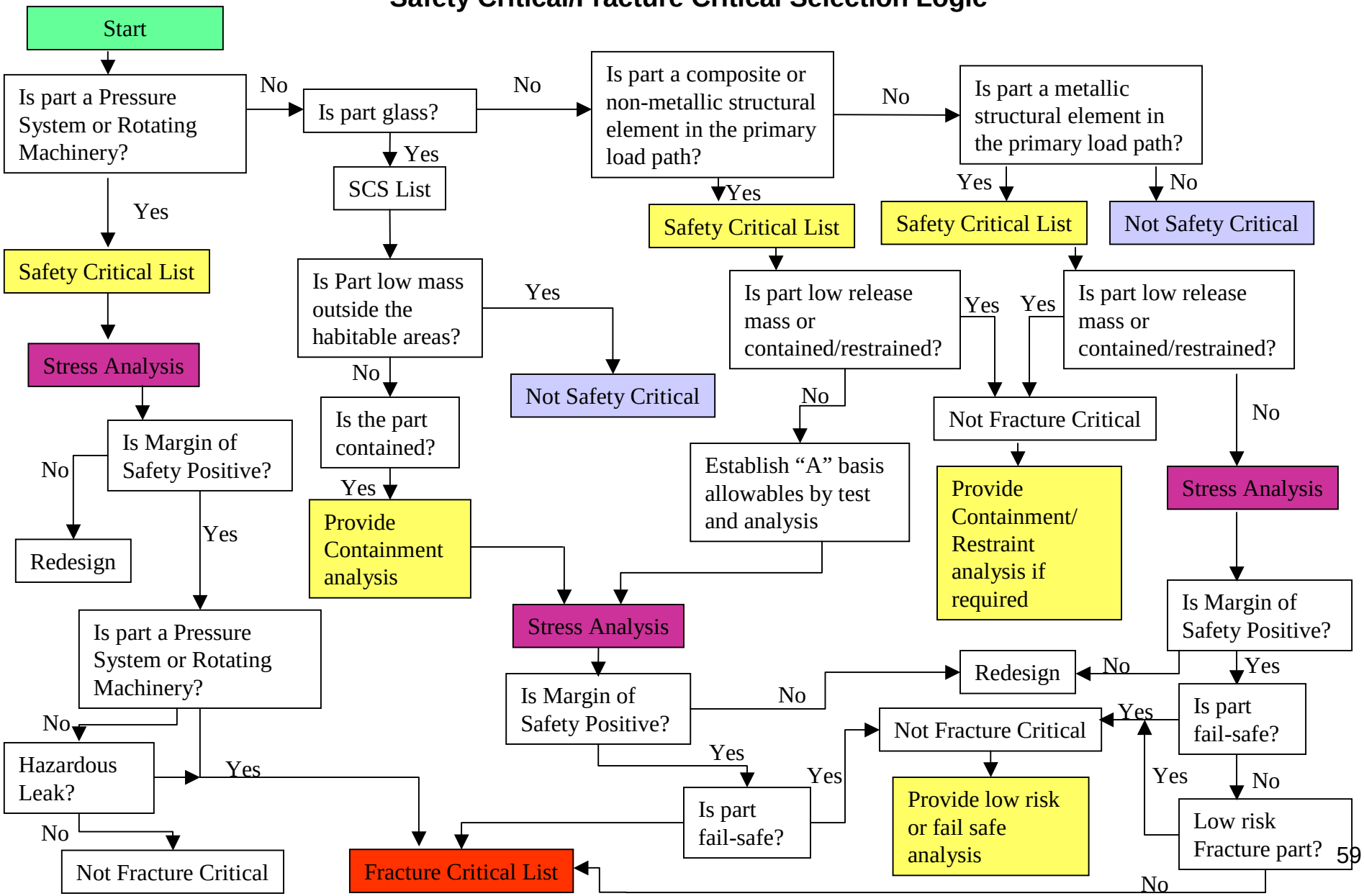
FCF Approach to Random Vibration Testing Flight and Qualification Hardware



Safety Critical/Fracture Critical Part Screening Process for Non-rotating, Metallic Components



Safety Critical/Fracture Critical Selection Logic



EMI Control Approach

- FCF Electromagnetic Interference/Compatibility Plan (FCF-PLN-0027) has been developed to provide requirements for EMI/EMC testing at both the subsystem and rack level.
- EMC compliance will be accomplished in two phases.
  1. Subsystem Level – EPCU as GFE, IOP, FCU IPP, DCM, PI, etc.

     Subsystem level testing may also include preliminary tests at the breadboard level for hardware believed to be at risk.
  2. Individual Rack Level – CIR, FIR, and SAR

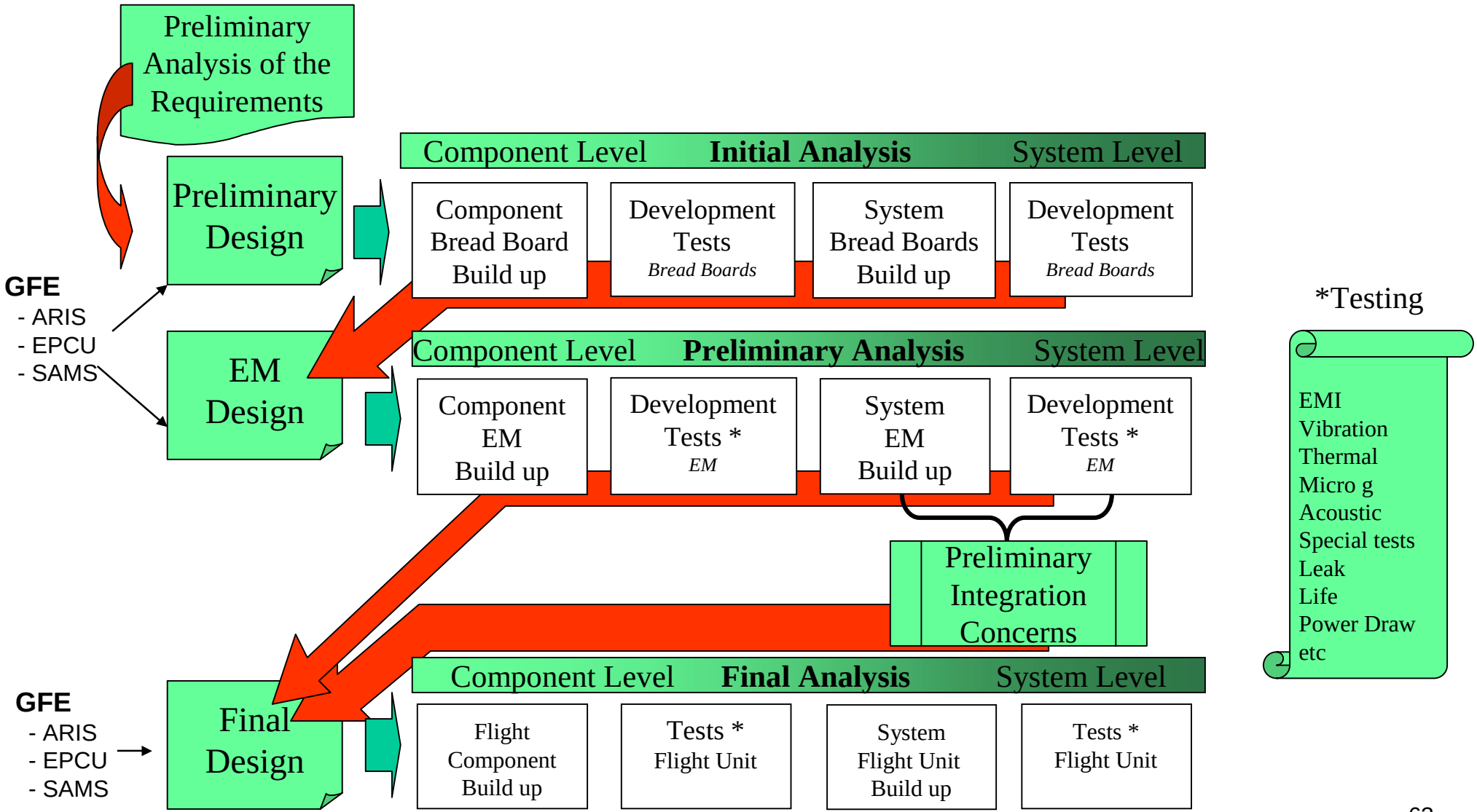
     Rack level requirements are well defined and understood. They have been performed on other ISS hardware by the GRC EMI Laboratory. Test levels and limits are defined in SSP 57000 and SSP 30237. Test methods are defined in SSP 30238.
- This subsystem design approach will be verified via successful rack level tests.
- Subsequent testing at the subsystem or box level will be used as justification for on-orbit replacement of existing hardware or the addition of new PI hardware.
- In cases where the hardware does not pass subsystem level test requirements, an analysis of the out of specification condition will be performed. This analysis will assess the potential impact on other subsystems as well as expected performance at the rack level.

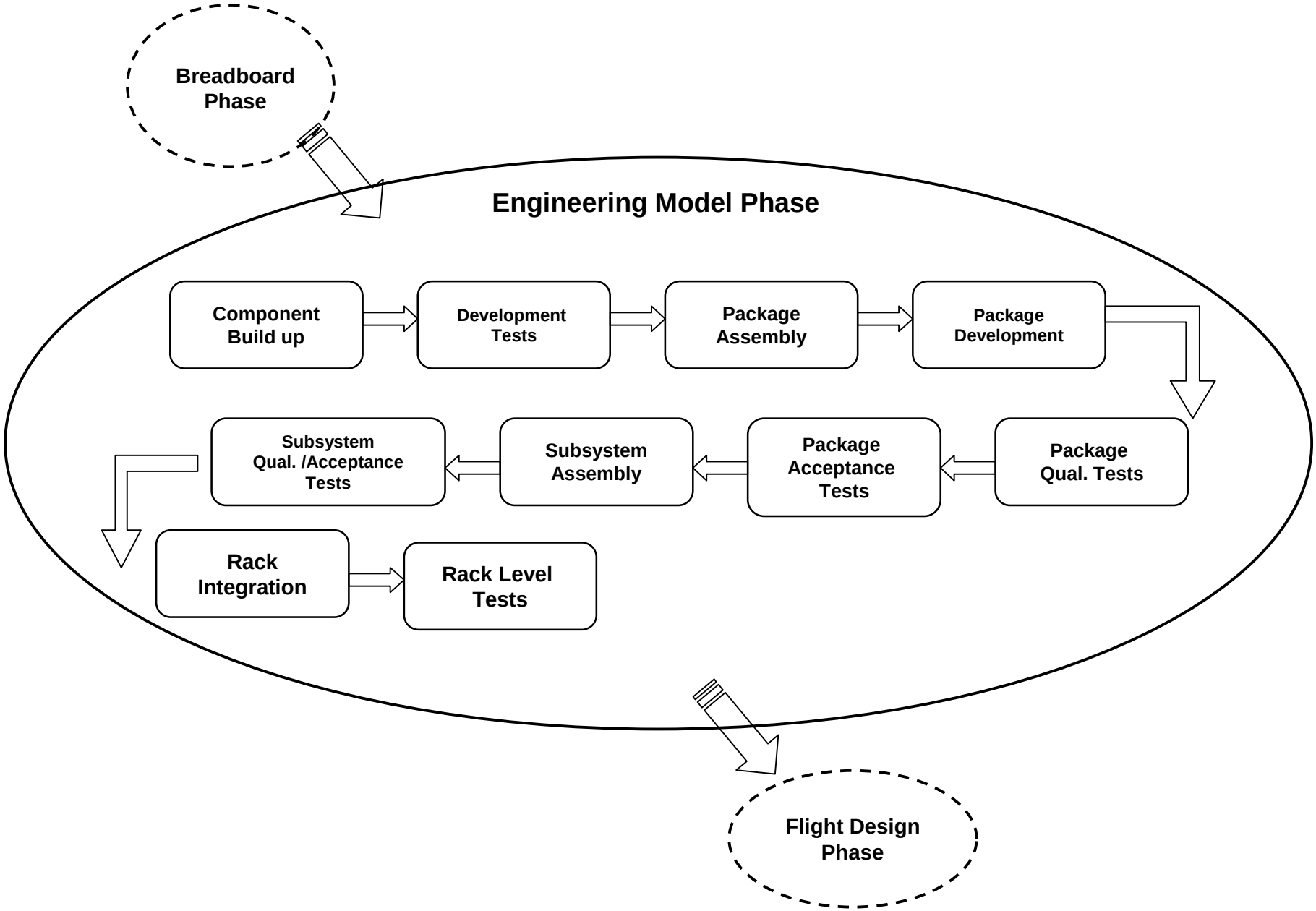
Status of FCF Analyses

- Initial Analysis
  - Functional (SRED compliance) — Complete
  - 57000 requirements — Complete
  - Safety Requirements — Complete
  - "A" Specification — Complete
- Preliminary Analysis
  - Functional (SRED compliance) — Complete
  - Structural (at the rack level) — In Work
  - Thermal (at the rack level) — In Work
  - Acoustic Noise — In Work
  - Microgravity including ARIS effects — In Work
  - Fit check of all components using Pro-E — Complete
  - 57000 requirements — Complete

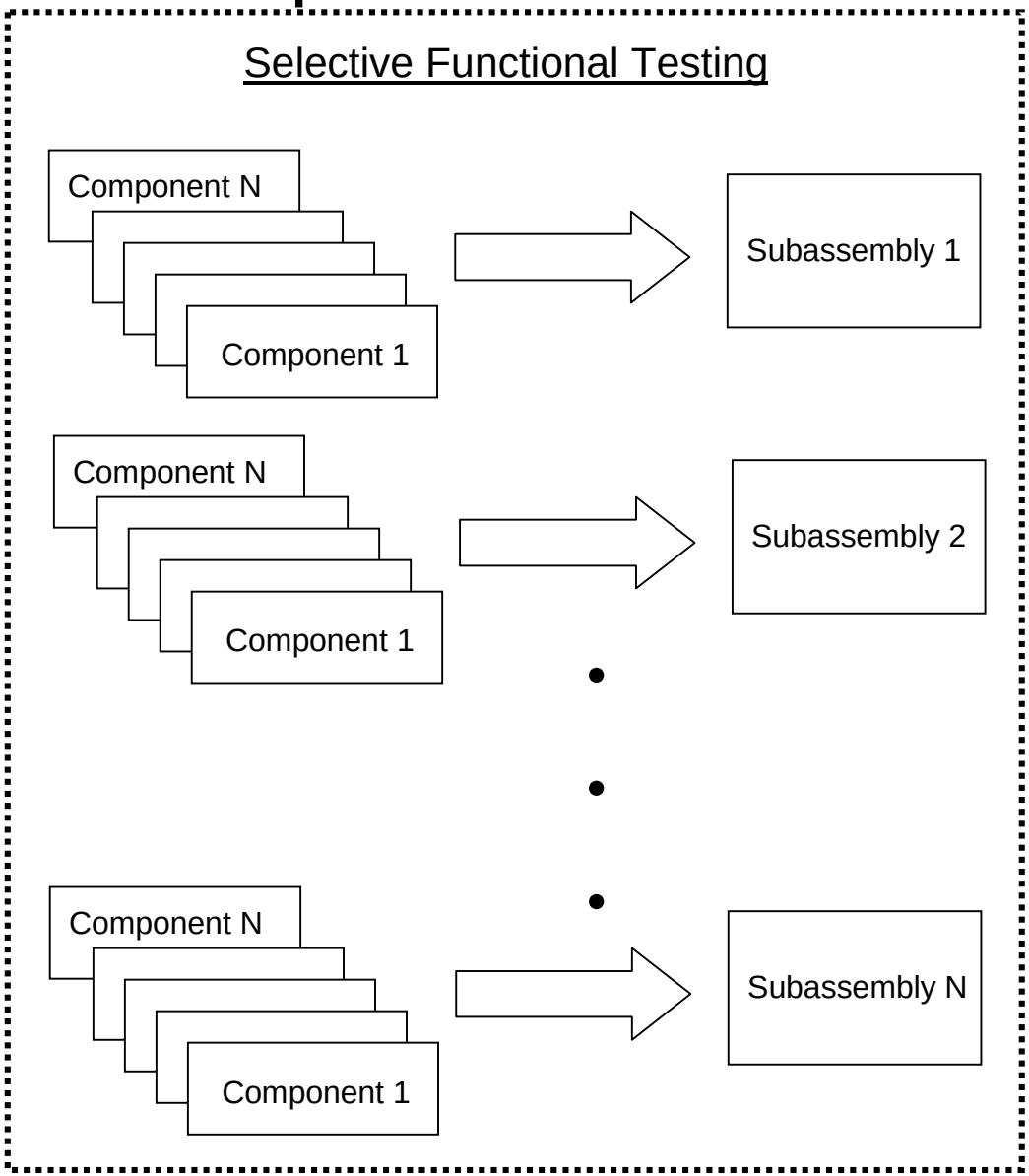
Development/Assembly and Integrated Test Approach and Processes

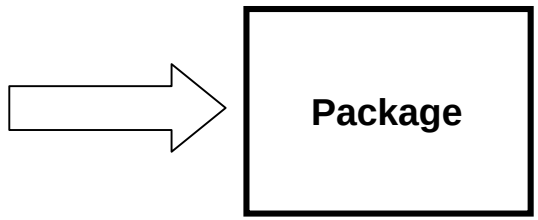
Development, Assembly and Integration Approach




Breadboard Phase
Engineering Model Phase
Component Build up
Development Tests
Package Assembly
Package Development
Package Qual. Tests
Package Acceptance Tests
Subsystem Assembly
Subsystem Qual. /Acceptance Tests
Rack Integration
Rack Level Tests
Flight Design Phase

EM Development & Test





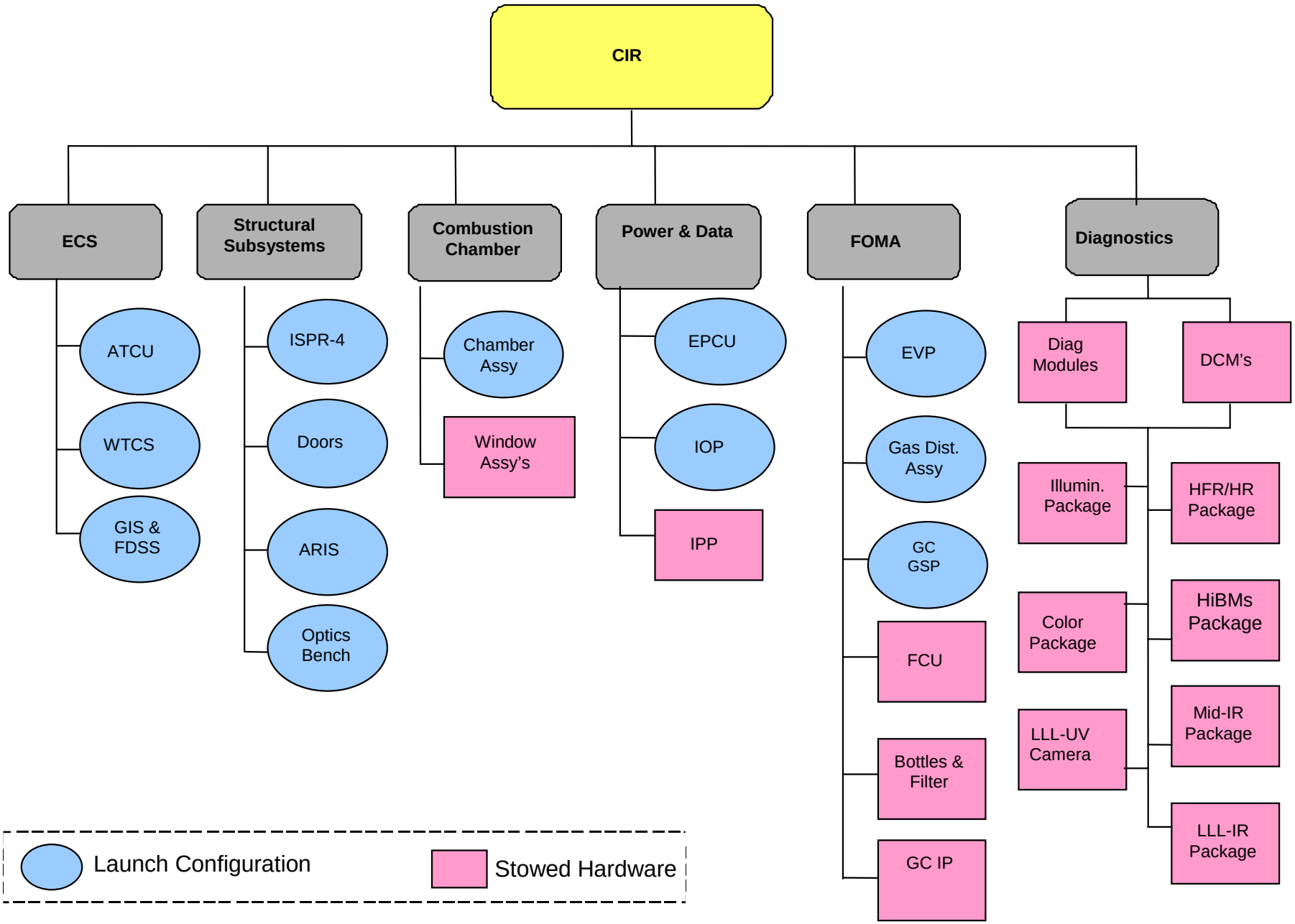
- Each package undergoes qualification and acceptance testing to verify that its design meets required performance parameters.
- Qualification and acceptance level testing of **all** packages accomplished using EM hardware configured in one of three ways, as appropriate:
  - as stand alone package
  - as part of a larger subsystem
  - as part of a partially integrated rack
- Each package and fully integrated rack also has a full range of EM acceptance testing.
  - EMI, acoustics, µg, power draw, pressure, thermal performance

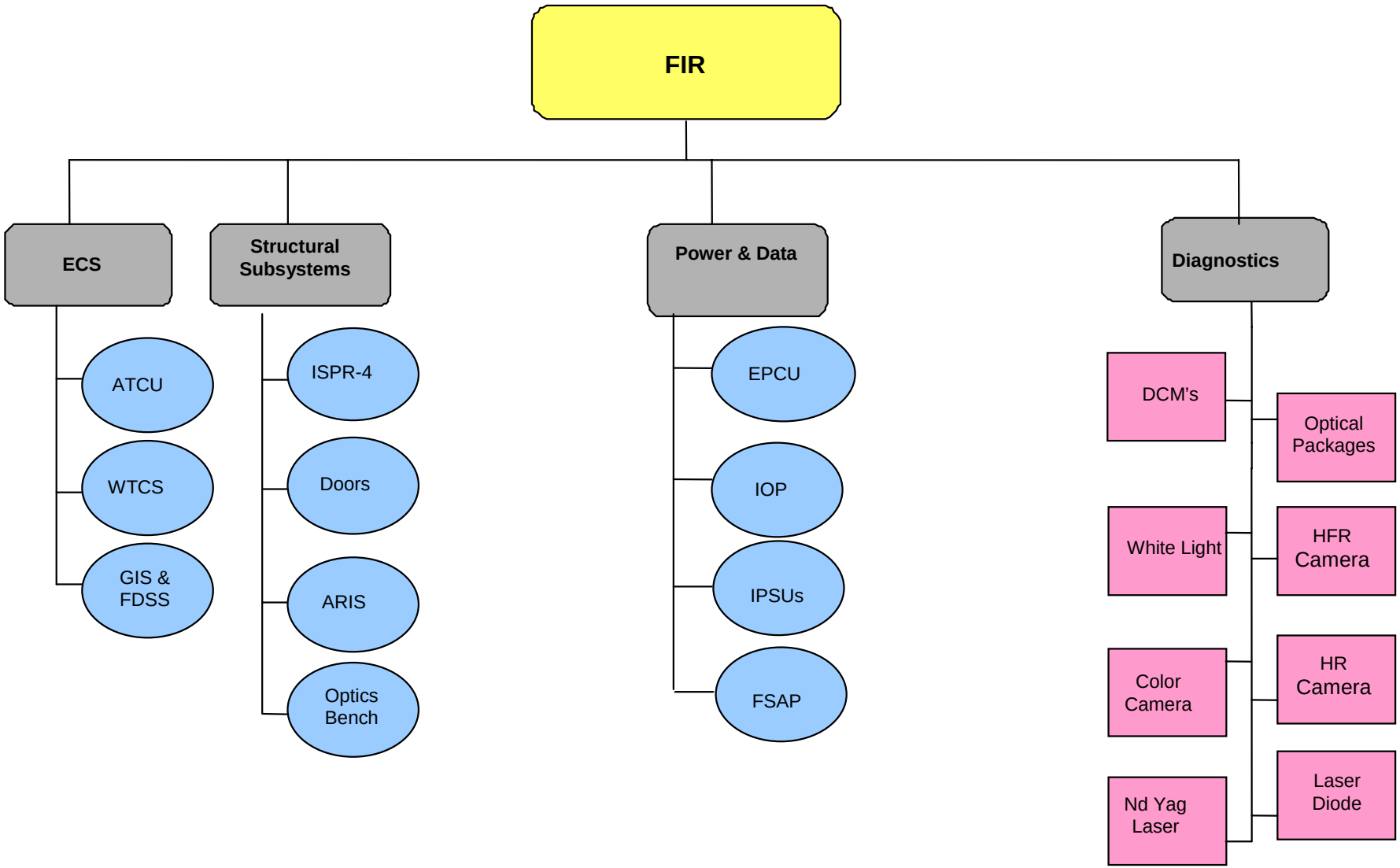
EM Development & Test - Qualification Testing

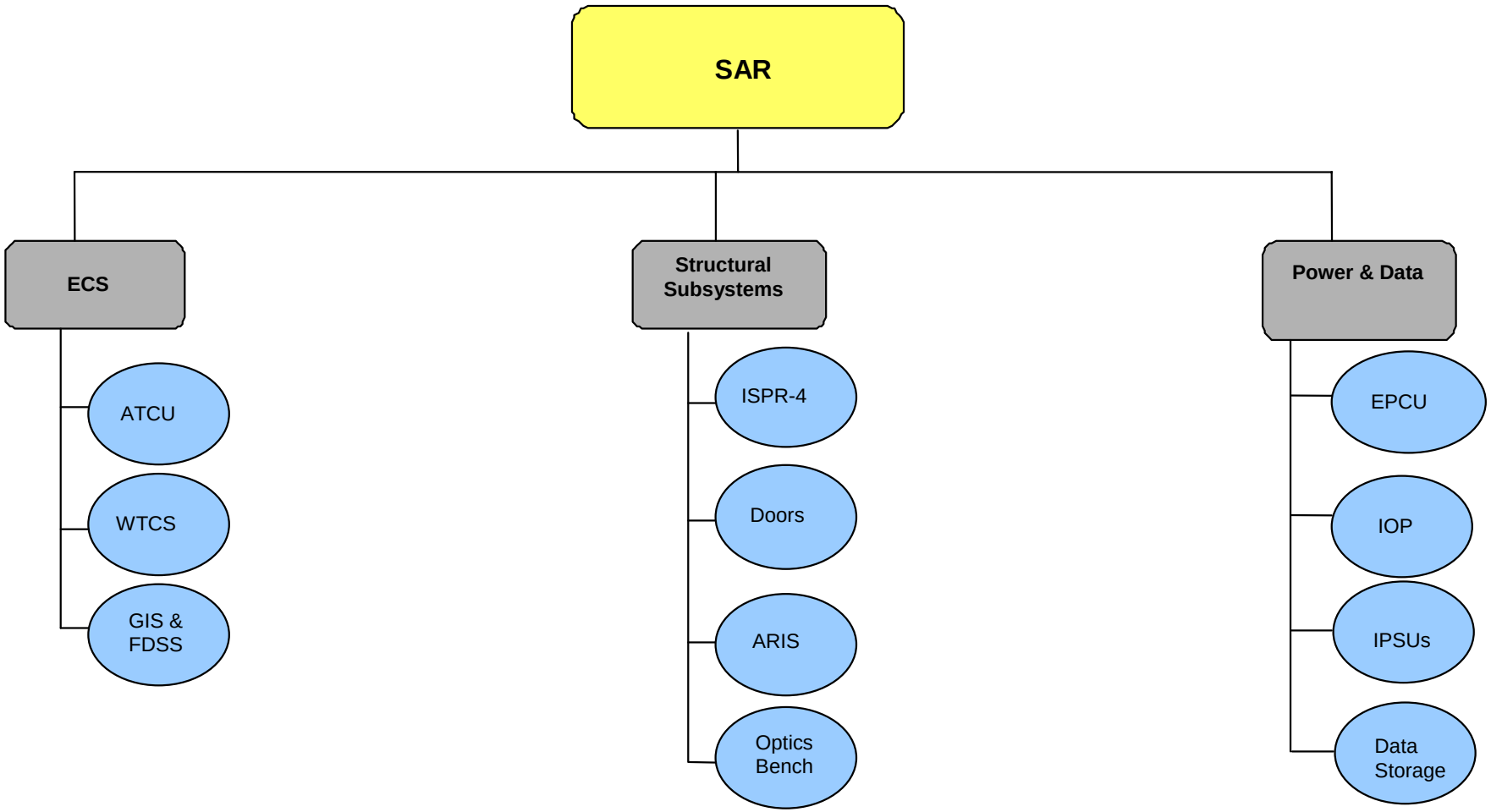
- Qualification Thermal Cycling testing is performed at the stand alone package level.
- Qualification vibration testing is performed with the hardware in an appropriate test configuration to ensure that test conditions reflect the real vibration environment the packages will see during launch. For the purpose of example, CIR vibration test configurations are shown.

Stand Alone Package	Integrated Subsystem	Partially Integrated Rack	Fully Integrated Rack
Unstowed at launch •EPCU •IOP Stowed at launch (a) •IPP •IPSU •GC •FCU •Diagnostic Pkgs	•Optics Bench, FOMA Pkgs & Chamber (CIR)* ** All packages mounted on Optics Bench in the launch configuration*	•ECS Components, FDSS, GIS and Rack Doors	•No vibration qualification testing at the fully integrated rack level

(a) Packages that are stowed during launch will be qual tested in their launch configuration; i.e., wrapped in foam and placed in a stowage container.


CIR
ECS
ATCU
WTCS
GIS & FDSS
Structural Subsystems
ISPR-4
Doors
ARIS
Optics Bench
Combustion Chamber
Chamber Assy
Window Assy's
Power & Data
EPCU
IOP
IPP
FOMA
EVP
Gas Dist. Assy
GC GSP
FCU
Bottles & Filter
GC IP
Diagnostics
Diag Modules
DCM's
Illumin. Package
HFR/HR Package
Color Package
HiBMs Package
LLL-UV Camera
Mid-IR Package
LLL-IR Package
Launch Configuration
Stowed Hardware


FIR
ECS
Structural Subsystems
Power & Data
Diagnostics
ATCU
WTCS
GIS & FDSS
ISPR-4
Doors
ARIS
Optics Bench
EPCU
IOP
IPSUs
FSAP
DCM's
Optical Packages
White Light
HFR Camera
Color Camera
HR Camera
Nd Yag Laser
Laser Diode
Launch Configuration
Stowed Hardware



Launch Configuration

Stowed Hardware

Use of PRCU and GIU to interface with flight racks for integrated testing

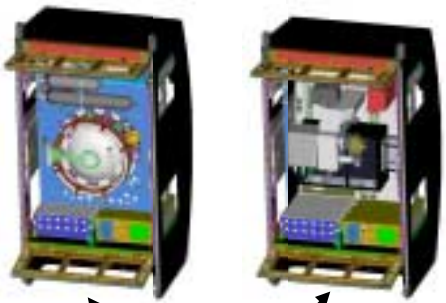
CIR
Flight Unit

PRCU

System testing

CIR
GIU

FIR
Flight Unit



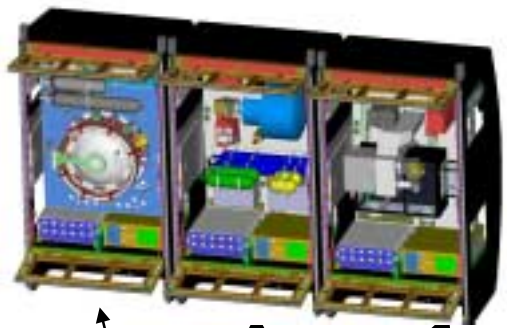
PRCU

System testing

CIR
GIU

SAR
Flight Unit

FIR
GIU

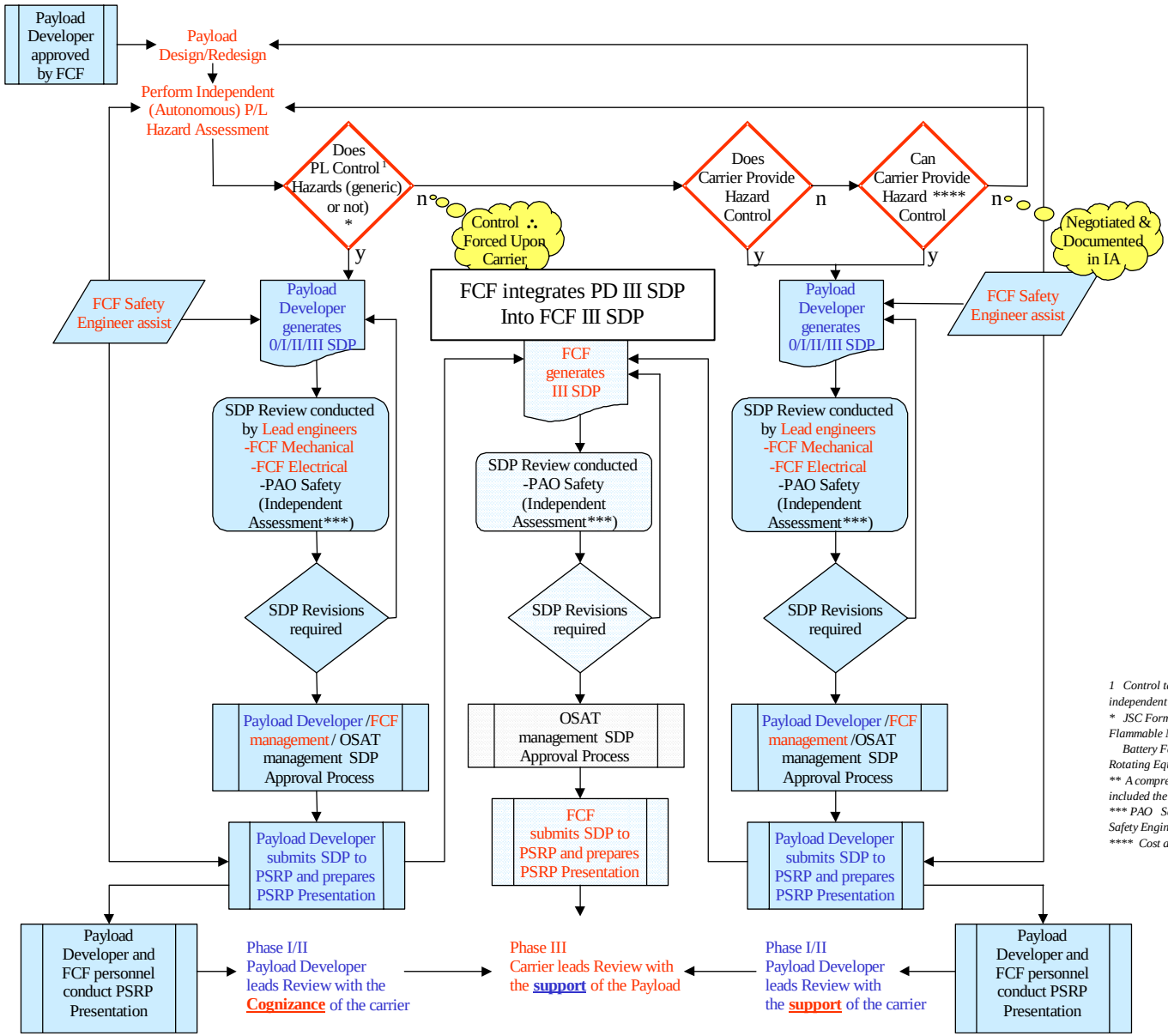


PRCU

System testing

Fluids Combustion Facility
Flight and Ground Safety

Fluids and Combustion Facility
Preliminary Design Review



1 Control takes into consideration the level of control (i.e. Catastrophic requires 3 independent controls, critical requires 2 independent controls)
** JSC Form 1230 (Structural Failure, Sharp Edges, Shatterable Material Release, Flammable Materials, Materials Offgassing , Nonionizing Radiation, Battery Failure,Touch Temperature, Electrical Power Distribution, Ignition, Rotating Equipment, Mate/ Demate Connectors, Rapid Safing)*
*** A comprehensive list of all payload hazards (Generic and Non-Generic) will be included the Integrated Phase III SDP*
**** PAO Safety Engineer who assists in the SDP Review is independent of the PAO Safety Engineer who assists in the development of the SDP as requested/negotiated*
***** Cost and Schedule impacts must be evaluated along with Technical Feasibility*

Carrier (FCF)
Payload (Payload Developer)
From OSAT Presentation
Derived from OSAT Presentation

Fluid Combustion Facility (FCF) Flight Safety Review/Package Approach

Combustion Integrated Rack (CIR)

- Safety Reviews Planned
  - Flight - Phase 0/1, II Reviews will be held independently
    - Phase III Flight Review will integrate the MDCA Facility Package
- Flight - Phase 0/1, II Safety Data Packages(SDP) will be prepared independently
  - Phase III Flight SDP will incorporate MDCA Phase III SDP

Fluids Integrated Rack (FIR)

- Safety Reviews Planned
  - Flight - Phase 0/1, II Reviews will be held independently
    - Phase III Flight Review will integrate the LMM Facility Package
- Flight - Phase 0/1, II Safety Data Packages(SDP) will be prepared independently
  - Phase III Flight SDP will incorporate LMM Phase III SDP

Shared Accommodation Rack (SAR)

- Safety Reviews Planned
  - Flight - Phase 0/1, II Reviews will be held independently
    - Phase III Flight Review will integrate the SAR Facility Package
- Flight - Phase 0/1, II Safety Data Packages(SDP) will be prepared independently
  - Phase III Flight SDP will incorporate SAR Phase III SDP

FCF Payload Flight Safety Review/Package Approach

Multi-User Droplet Combustion Apparatus (MDCA)

- Safety Reviews Planned
  - Flight - Phase 0/1, II Reviews will be held independently
    - Phase III Flight Review will be integrated with CIR Facility
- Flight - Phase 0/1, II Safety Data Packages(SDP) will be prepared independently
  - Phase III Flight SDP will be prepared and integrated with CIR Phase III SDP

Light Microscopy Module (LMM)

- Safety Reviews Planned
  - Flight - Phase 0/1, II Reviews will be held independently
    - Phase III Flight Review will be integrated with FIR Facility
- Flight - Phase 0/1, II Safety Data Packages(SDP) will be prepared independently
  - Phase III Flight SDP will be prepared and integrated with FIR Phase III SDP

Payload for Shared Accommodations Rack (SAR)

- Safety Reviews Planned
  - Flight - Phase 0/1, II Reviews will be held independently
    - Phase III Flight Review will be integrated with CIR Facility
- Flight - Phase 0/1, II Safety Data Packages(SDP) will be prepared independently
  - Phase III Flight SDP will be prepared and integrated with SAR Phase III SDP

Fluids Combustion Facility/Payload Ground Safety Approach

- Multi-User Droplet Combustion Apparatus (MDCA) Safety Reviews Planned
  - Ground - Phase II & III
    - Reviews will be held in conjunction with the CIR Facility Ground Review
  - Ground Payload Safety Review Packages will be prepared Independently
- Light Microscopy Module (LMM) Safety Reviews Planned
  - Ground - Phase II & III
    - Reviews will be held in conjunction with the FIR Facility Ground Review
  - Ground Payload Safety Review Packages will be prepared Independently
- Payload TBD for Shared Accommodations Rack (SAR) Safety Reviews Planned
  - Ground - Phase II & III
    - Reviews will be held in conjunction with the SAR Facility Ground Review
  - Ground Payload Safety Review Packages will be prepared Independently

Flight Safety Status

- Flight Facility Safety
  - Combustion Integrated Rack (CIR) – Flight Safety
    - CIR Phase 0/1/Delta Phase 0/1 Flight Safety Review Completed Successfully
    - CIR Phase II Flight Safety Review will be scheduled for TBD
  - Fluids Integrated Rack (FIR) – Flight Safety
    - FIR Phase 0 Flight Safety Review completed successfully.
    - FIR Phase I Flight Safety Review completed successfully.
- Flight FCF Payload Safety
  - Multi-User Droplet Combustion Apparatus (MDCA) – Flight Safety
    - MDCA Phase 0/1 Flight Safety Review Completed
    - MDCA Phase II Safety Review will be scheduled for TBD
  - Light Microscopy Module (LMM) – Flight Safety
    - LMM Phase 0/1 Flight Safety Review scheduled for March, 2001
    - LMM Phase II Flight Safety Review scheduled for March, 2001

Ground Safety Status

Ground Facility Safety

- Combustion Integrated Rack (CIR) – Ground Safety
  - CIR Phase II Ground Review Scheduled for TBD

- Fluids Integrated Rack (FIR) – Ground Safety
  - FIR Phase II Ground Review Scheduled for TBD

Ground FCF Payload Safety

- Multi-User Droplet Combustion Apparatus (MDCA) – Ground Safety
  - MDCA Phase Draft Ground Safety Package Completed Review to be scheduled.
  - MDCA Phase II Ground Review Scheduled for TBD

- Light Microscopy Module (LMM) – Ground Safety
  - LMM Phase Draft Ground Safety Package to be completed.
  - LMM Phase II Ground Review Scheduled for TBD

Safety Key Requirements Compliance

- No non-compliances
- FIR Phase I Review - January 30 & 31, 2001
  - –System Laser Safety approach
  - –Fluids containment supplied by PI
- CIR Phase 0/1 complete, Phase II in July 01
  - –FOMA system which provides gases has been through safety process and White Sands O2 analysis
  - –CIR provides Chamber and equivalent 2 levels of containment
  - –System Laser Safety approach

Differences Between EDU, GIU and Flight Segment

Differences between EDU, GIU and Flight Segment

- Breadboard
  - Hardware
    - New hardware and EM hardware
    - Hardware functionally similar to flight hardware
    - Supported with necessary GSE (including structural support)
  - Function
    - Will functionally similar to flight unit
    - Used by PI's to test feasibility of hardware/concepts System Specification

Differences between EDU, GIU and Flight Segment

•EDU

– Hardware

Qualification units, Functional equivalent and EM hardware

Complete set of hardware as in flight unit (sans ARIS and SAMS)

Supported with necessary GSE (including structural support)

– Function

Will functionally equivalent to flight unit

Used by PI’s to develop flight hardware

Differences between EDU, GIU and Flight Segment

•GIU

– Hardware

Flight Pedigree hardware. (Drawings will be flight hardware drawings).

Hardware will be functionally tested as flight hardware was but not environmentally tested.

Quality will be same as flight unit.

Complete set of hardware as in flight unit (sans ARIS and SAMS) Supported with necessary GSE (including structural support). PRCU will supply water, power and vacuum

– Function

Will functionally equivalent to flight unit.

Used by PI's for integration verification, Flight S/W update validation, trouble shooting, and following on orbit progress. Procedure development, verification of system level requirements between racks (see chart)

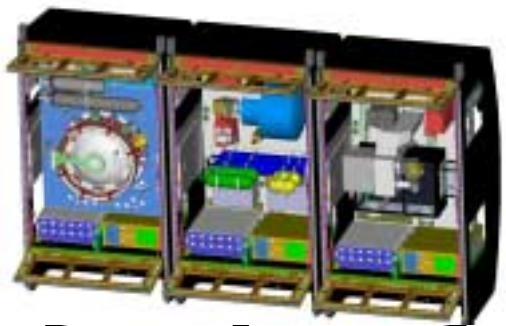
PI Breadboard & Functional Model H/W

Request to Test

PI Flight H/W

Request to Test

EDU



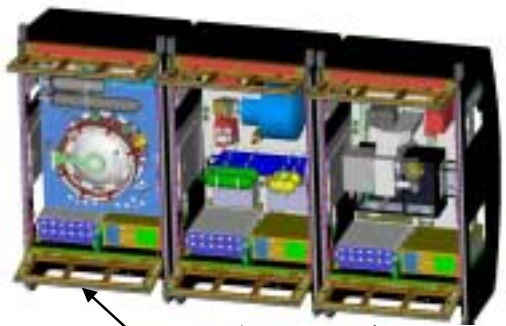
GSE Chiller

GSE Power

GSE Vacuum

GSE

GIU

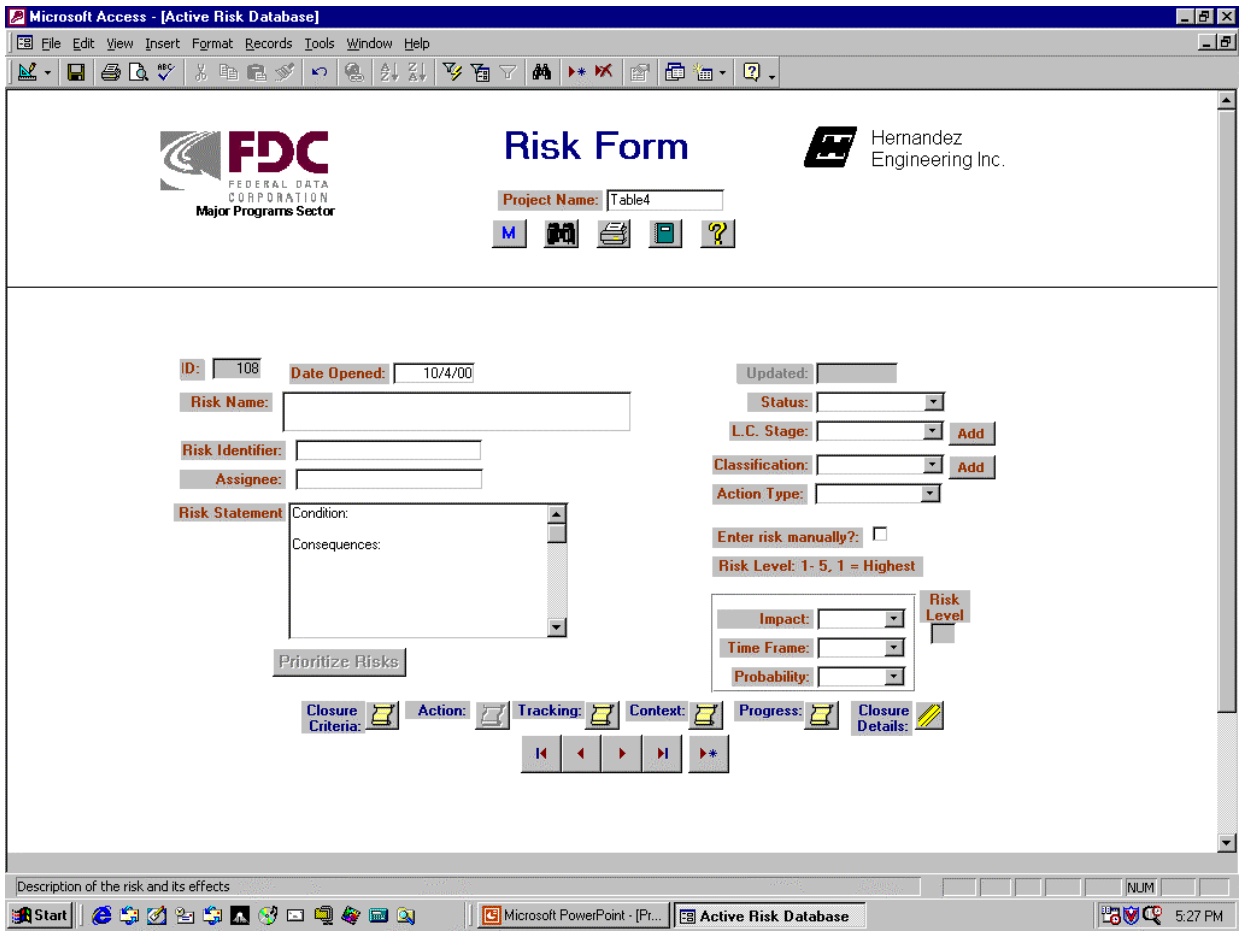


PRCU

FCF Level Risks

Risk Management

• All risks for the FCF are identified and assessed by the FDC team. These risks are then tracked in the MRDOC automated Risk Status and Tracking System. Risks are reviewed weekly by the PDT Leads, assessing the progress of risk mitigation activities.



Top Risks for FCF System

The following issues represent significant risk to the FCF's ability to meet mission objectives. An FCF mitigation plan has been developed for each risk area:

- Microgravity disturbances
  - addressed by Microgravity Control Plan
- Acoustic noise
  - addressed by Acoustic Noise Control Plan
- Radiation effects on electronics
  - mitigation and control plan in work

Risk items associated with a particular rack are addressed at the rack level.

In all, 45 active risks are currently being tracked by the FDC Team.

- Developed a formal Risk Management Plan FCF-PLAN-0046 which establishes structured risk management processes.
- Established a risk database to track and control project risks.

Identify	Capturing statements of risk Capturing the context of a risk
Analyze	Evaluating attributes of risk Classifying risks Prioritizing risks
Plan	Assigning responsibility Determining approach Defining scope and actions
Track	Related data is aquired, compiled, analyzed, and reported *Note: Risks can be tracked individually or in sets*
Control	Decisions made based on the data presented in the tracking reports *Note: Risks can be controlled individually or in sets*

Continuous Risk Management

Communication and documentation shall be performed through out the continuous risk management process

Impact Definitions

Loss of entire system
Severe Down Time > 30 days
Catastrophic

Major system damage
Significant down time 1 – 30 days
Critical

Minor system damage
Minor down time < 1 day
Marginal

No system damage
Insignificant down time < 1 hour
Negligible

Risk Priority Matrix

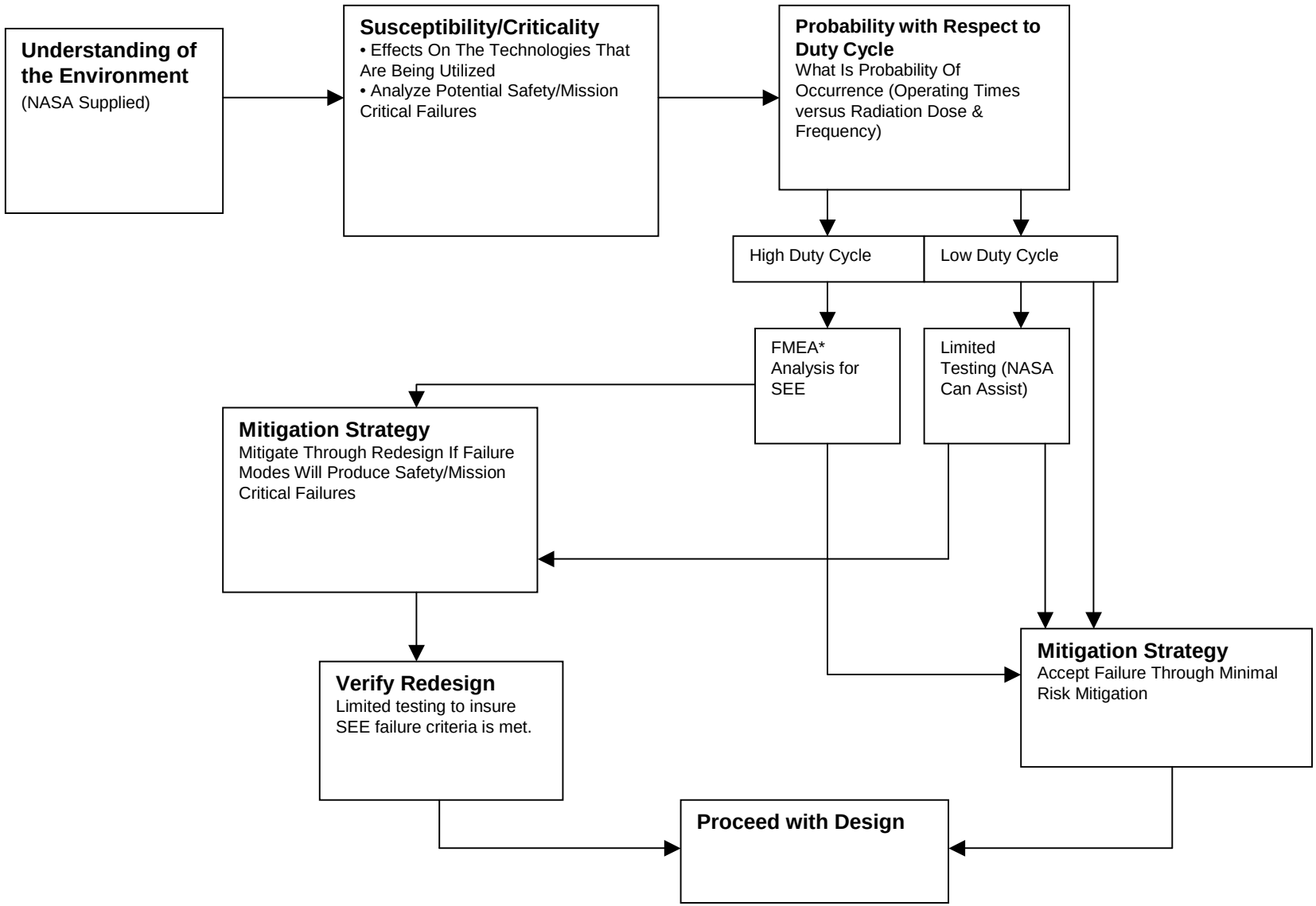
From MRD-DOC-0006 (Risk Management Plan)

Severity Level	Likelihood of Occurrence: Probable	Occasional	Remote	Improbable
Catastrophic	1	1	2	3
Critical	1	2	3	4
Marginal	2	3	4	5
Negligible	3	4	5	5

Key

1	HIGH
2	MEDIUM HIGH
3	MEDIUM
4	MEDIUM LOW
5	LOW

Flowchart For Radiation Effects Analysis



*Standard FMEA will be performed on all packages. These FMEA's look specifically for SEE

Radiation Effects Analysis - Subsystem Priority Listing

- Primary
  - Common IOP (Tom Young/Mike Casciani)
  - Common ECS (Tracy Neff/John Siamidis)
  - FIR FSAP (Tom Young/Bart Gruber)
  - CIR FCU (Myron Wilkinson/Mary Domo)
- Secondary
  - FOMA & Combustion Chamber (TBD)
  - CIR IPP, Common IPSU (TBD)
  - Science Diagnostics/DCM (TBD)

Radiation Effects Mitigation Plan

- Environmental profile has been established.
- Gather data (parts lists) for initial analysis of radiation effects.
- Determine probability of occurrence.
- Test/Analyze based upon above factors.
- Mitigate through acceptance or redesign.

FCF System Compliance

Common Hardware Non-compliances

- Captive Fasteners on Several Components
  - Components include:
    - Optics Bench Attachment Hardware
    - Door Launch Restraints
    - Rack Attachment Hardware for ATCU, EPCU, and IOP
  - Mitigation strategy includes:
    - Identifying and assessing candidate alternatives
    - If necessary, rationale for potential waiver is one-time of operation of these fasteners for rack setup or ORU failure
    - Resolution should occur by April 2001

Common Hardware Non-compliances

- Diagnostics Package Pin ID, Connector Arrangement, and Ease of Disconnect
  - –All affected by use of Airborn Connectors on several packages
  - –Rationale for seeking waiver is infrequency of operation of these connectors and inability to obtain packing density with larger connectors that meet current 57000 requirements
  - –Waiver to be submitted by April 2001

Common Hardware Non-compliances

- IPP Accessibility
  - –Installation and removal of the IPP involves mating and demating an electrical connector – the UML ARINC connector
  - –When installed in the CIR, the IPP will be bolted to the optics bench
  - –Because of their close proximity, it may not be possible to install or remove the IPP without removing adjacent diagnostic packages
  - –If crew consensus is obtained at the crew review, will seek a waiver of this requirement by June 2001

Summary of Issues

FCF System Issues

The following items are significant issues relative to the FCF's ability to meet requirements:

ISS Resource Issues

- FCF system spec power constraint of 2000 watts
- Data downlink available for experiment data

FCF Design Issues

- Diagnostics and other bench mounted components cannot meet Kick Load requirement

Notes